frontiers in Earth Science

REVIEW
published: 06 November 2018
doi: 10.3389/feart.2018.00184

A Review of Studies on Participatory Early Warning Systems (P-EWS): Pathways to Support Citizen Science Initiatives

Victor Marchezini[1,2], Flávio Eduardo Aoki Horita[3], Patricia Mie Matsuo[4], Rachel Trajber[1], Miguel Angel Trejo-Rangel[2] and Débora Olivato[1]*

[1] Centro Nacional de Monitoramento e Alertas de Desastres Naturais, São José dos Campos, Brazil, [2] Programa de Pós-Graduação em Ciência do Sistema Terrestre, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brazil, [3] Centro de Matemática Computação e Cognição, Universidade Federal do ABC, São Paulo, Brazil, [4] Programa de Pós-Graduação Interunidades em Ensino de Ciências, Universidade de São Paulo, São Paulo, Brazil

Context: Global environmental change and disasters pose several challenges to governments, society and science. These challenges occurred in social contexts were information and communication technologies can be used to share data and information, engaging citizen scientists in multidirectional and decentralized knowledge creation initiatives. Often referenced as participatory (or people-centered) early warning systems, this has been of a great potential to improve decisions taken by both emergency institutions and exposed and/or affected communities. Several methodologies have been proposed, mainly in natural science, redefining traditional ways of transferring knowledge about scientific process to the public.

Gap: However, practice and research still lack studies that investigate how citizens can be involved in citizen science to support early warning systems. From a social science perspective, this is important as these works do not fill the gap between citizen science and disaster prevention. While, on a technological perspective, efforts have been concentrated on developing systems, methodologies, and approaches rather than understanding citizens' requirements or ways of better engaging citizens.

Objective: This paper provides a social science framework to determine the elements of how citizen science and participatory early warning systems can be bridged.

Method: For doing so, we will conduct a systematic mapping for examining the literature on citizen science and disaster management, in particular, those focused on social science and participatory approaches for early warning systems.

Results: This review showed that only 3,43% (14 of 408) articles were related to citizen science and P-EWS, which indeed indicate that much effort is needed to disseminate what is citizen science and how it can be mainstreamed in DRM field. Furthermore, the proposed framework can contribute by enhancing stakeholders' reflexivity about EWS.

Keywords: community-based disaster risk management, capacity building, resilience, interdisciplinary, transdisciplinary

Edited by:
Jonathan D. Paul,
Imperial College London,
United Kingdom

Reviewed by:
Davide Tiranti,
Agenzia Regionale per la Protezione Ambientale (ARPA), Italy
Samuele Segoni,
Università degli Studi di Firenze, Italy

****Correspondence:***
Victor Marchezini
victor.marchezini@cemaden.gov.br

Specialty section:
This article was submitted to Geohazards and Georisks, a section of the journal Frontiers in Earth Science

Received: *30 August 2018*
Accepted: *12 October 2018*
Published: *06 November 2018*

Citation:
Marchezini V, Horita FEA, Matsuo PM, Trajber R, Trejo-Rangel MA and Olivato D (2018) A Review of Studies on Participatory Early Warning Systems (P-EWS): Pathways to Support Citizen Science Initiatives. Front. Earth Sci. 6:184. doi: 10.3389/feart.2018.00184

INTRODUCTION

In 2016, the United Nations International Strategy for Disaster Reduction (Unisdr) conducted an international conference to discuss the role of Science and Technology (S&T) on the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR). The 2016 S&T Conference aimed to find pathways to expand science's impact on disaster risk reduction (DRR) strategies, building networks among practitioners, policymakers and scientists from different fields of knowledge and expertise (Aitsi-Selmi et al., 2016). One of the working groups focused on how to coordinate the agenda of disaster risk science with the requirements of innovation in interdisciplinary methods, robust data collection, tools and better communication systems, especially in early warning system (EWS).

The most updated definition of EWS provided by United Nations International Strategy for Disaster Reduction [UNISDR] (2016) framed it as an integrated system that comprises disaster risk assessment, hazard forecast, prediction and monitoring, risk communication and emergency preparedness activities. As a set of capacities, data, information and knowledge that allow the early action of individuals and communities exposed to hazards to prepare and evacuate in an appropriate manner and in adequate time to reduce the likelihood of loss of life, personal injury, losses and damages (United Nations International Strategy for Disaster Reduction [UNISDR], 2009). EWS then should combine four complementary elements–risk knowledge, monitoring, communication of warnings, and response capability (United Nations International Strategy for Disaster Reduction [UNISDR], 2005, 2006a,b, 2015). The scientific literature has been adopting *two main approaches of EWS* - the "last mile" (hazard-centered and top down) and "first mile" (people-centered and bottom up) (Basher, 2006; Thomalla and Larsen, 2010; Garcia and Fearnley, 2012; Villagrán de León, 2012; Kelman and Glantz, 2014). This work will lie on the "first mile" approach, focusing on people-centered EWS (United Nations International Strategy for Disaster Reduction [UNISDR], 2005, 2006b), community early warning systems - CEWS (International Federation of the Red Cross and Red Crescent Societies [IFRC], 2012), community-centric EWS (Baudoin et al., 2016), community-based EWS (Macherera and Chimbari, 2016a), participatory EWS (Baudoin et al., 2016; Marchezini et al., 2017).

There is a growing recognition that "last mile" approach is not sufficient to reach the aims of EWS. The EWS' working group of Unisdr S&T Conference, for instance, stated that despite the improvements in remote sensing technology, space-based satellite systems and computer technology for observing, comprising real-time data collection, modeling capability and dissemination of information, *communication* still needs to be critical to the success of EWS (Aitsi-Selmi et al., 2016). Remembering the critics about the EWS' failures during the 2004 Indian Ocean Tsunami (Kelman, 2006) – when around 230,000 people died – researchers stressed the importance of people-centered approaches and the need to identify capacities of different countries for EWS implementation. Not only the international, regional and national partnerships were stressed as important, but also the local level capacity to ensure involvement and ownership in EWS. More specifically, the need to consider the user voices from across society and engaging them in EWS were highlighted as essential (Aitsi-Selmi et al., 2016). However, as we will discuss in the section 2 of this paper, there are many *forms of engagement and participation* in these people-centered approaches.

Although previous studies have stated that Unisdr lacks explicit means for implementing people-centered approaches and bottom-up design (Nguyen et al., 2009; Paveglio et al., 2010; Garcia and Fearnley, 2012; Zia and Wagner, 2015), the 2016 S&T Conference did not mention the need of research to discover how to promote people-centered EWS (Aitsi-Selmi et al., 2016). Some working groups recognized the need of bottom-up and participatory approaches in disaster risk research, and considered that such collaborations to co-producing knowledge "could include (but are not limited to) the incorporation of indigenous perspectives and knowledge and using a variety of 'citizen science' programs" (Aitsi-Selmi et al., 2016, p. 18). Citizen science refers to the engagement of the public in data collection, data analysis, information sharing, and knowledge co-production (Teschenhausen, 2015). However, there are different forms of participation (informing, consulting, co-creating etc.) and models of cooperation in citizen science (contributive, collaborative, co-created) (Bonney et al., 2009).

On a technological perspective, efforts have been concentrated on developing systems, methodologies, and approaches rather than understanding citizens' requirements or ways of better engaging citizens in EWS (Villagrán de León et al., 2006; Quansah et al., 2010; Kou and Wu, 2014; Horita et al., 2017). In contrast, practice and research still lack studies that investigate how citizens can be involved in citizen science to support early warning systems. This is important because local citizens are the true first responders to mobilize during emergencies and they have a critical role in saving lives and to render assistance to those in need (Glantz and Ramírez, 2018). This paper provides a social science framework to determine the elements of how citizen science and participatory early warning systems can be bridged. For doing so, we conduct a review that examines the existing literature on citizen science and disaster management, in particular, those focused on social science and participatory approaches for early warning systems, complementing previous systematic review of community-based EWS (Garcia and Fearnley, 2012; Macherera and Chimbari, 2016a).

This paper is structured as follows. Section 2 provides the theoretical background about the two main approaches of EWS, forms of engagement and participation, and models of cooperation in citizen science. Section 3 then describes the research methodology, while Section 4 details the study results. Section 5 discusses these results and introduces the social science framework. Finally, Section 6 draws some conclusions and final considerations.

THEORETICAL BACKGROUND

Early Warning Systems

EWSs are a social process with diverse levels of complexity, vulnerabilities and capacities due the varied political and socioeconomic contexts where they work (Garcia and Fearnley, 2012; Michoud et al., 2013; Kelman and Glantz, 2014; Lumbroso et al., 2016). Moreover, there are different characteristics, types and frequencies of hazards (rapid, slow) and variations in spatial scale (local, regional, national, and global), besides the number of stakeholders involved in the EWS (civil authorities, enterprises, scientists, media, communities, practitioners, and technicians).

Gray and scientific literature have some consensus regarding the importance of the four components of the EWS: risk knowledge, monitoring, communication and response capability. However, the different approaches regarding each of the four axes imply diverse definitions. In this paper, we consider risk knowledge as a systematic data collection and analysis of hazards and vulnerabilities – physical, social, economic, and environmental – that merge in risk scenarios subject to changes in the short and long term (Marchezini et al., 2017). Monitoring implies the capacities for collecting dynamic data and information and for analyze them on the basis of prior knowledge to take decisions. Communication is the process of sharing data, information and knowledge about the risks and warning situations. Response capability is the preparedness capacity to know how to act and is often rooted in resources, skills and networks that stakeholders have. Local governments, for instance, can be more capable when hold sufficient personal, clear structure, proper tasks, delegation and division of labor within the organization (Kusumasari and Alam, 2012).

The traditional conception of EWS conceives it as linear chain with emphasis on risk prediction, monitoring and warning issuance (Basher, 2006). In this approach, EWS are frequently operated by regional or national agencies in charge of risk diagnosis and dissemination of alerts to local authorities and stakeholders. This one-way course is named as the "End-to-End" model (Basher, 2006) and does not directly engage with the users of the EWS in the four-interrelated elements. In this one-way chain, the strong links are technological in nature (risk knowledge and monitoring) whereas communication and response capability are the weak links (Garcia and Fearnley, 2012). This approach has also been named as "last mile," because people are the last to be involved in the system. In this top-down approach, people are not at the center of the social process. The technical equipment (for example, radar and rainfall gauges) detects a hazard and issues alerts to vulnerable people, who are not viewed as being supplied with information and knowledge, or endowed with applicable wisdom. This approach assumes that all the relevant data, information, and knowledge are outside the local communities, placing emphasis on technological and scientific factors. For instance, the checklist of United Nations International Strategy for Disaster Reduction [UNISDR] (2006a) about EWS implementation states the monitoring is the core of the system, but did not cite the importance of participation in this component of EWS.

Other conceptions advocate for more participation in each of the four interrelated components of EWS, and are named the "first mile" approach because put people at first in designing and operation of the system. In this "horizontal" model, multiple stakeholders must be in dialog and cooperation at every phase of the process (Gaillard and Mercer, 2012). To make this approach effective, system planners must comprehend the different types and degrees of vulnerability and capability of people. In other words, the EWS must consider *who are the people* and examine the interconnection of social dimensions such as human mobility and demographic characteristics, occupation, religion, culture, language, gender relations, sexuality, ethnicity, race, age, persons with disabilities, refugees, livelihoods and environmental change over time. Gender, for instance, means "the socio-culturally and politico-economically constructed roles and responsibilities ascribed to men and women, girls, boys and members of sexual and gender minorities, which change over time, are context- and history-specific, and are inseparable from power relations" (Mustafa et al., 2015, p. 2). Gender relations shape differentiated access to rights and resources – healthcare services, education, transportation, access to information -, and will define, for example, our ability to prepare, cope with, and "be resilient or not" in the wake of hazards.

"First mile" approach has been represented by a variety of names such as people-centered EWS (United Nations International Strategy for Disaster Reduction [UNISDR], 2005, 2006a), community early warning systems – CEWS (International Federation of the Red Cross and Red Crescent Societies [IFRC], 2012), citizen-centered EWS (Mustafa et al., 2015), community-centric EWS (Baudoin et al., 2016), community-based EWS (Macherera and Chimbari, 2016a), participatory EWS (Baudoin et al., 2016; Marchezini et al., 2017).

Community-based early warning system (CBEWS) is defined "as one in which the communities participate in hazard identification and the formulation of the warning system, and not merely reacting to a warning at local level" (Macherera and Chimbari, 2016a, p. 3). According to Macherera and Chimbari (2016a, p. 9), for the International Federation of Red Cross and Red Crescent Societies (IFRC), the term "community"-based early warning systems "does not really imply community participation, but may mean a system that is based at community level but implemented by other agencies". International Federation of the Red Cross and Red Crescent Societies [IFRC] (2012, p. 13) states that community early warning systems (CEWS) is better because "is understood to be an effort by or with, but not for, a community to systematically collect, compile and/or analyze information that enables the dissemination of warning messages that when actionable can help the community (or others 'downstream') reduce harm or loss from a hazard (or threat) event (or process)". Inspired by this IFRC's definition, Baudoin et al. (2016, p. 164) proposed the concept of "community-centric" EWS (CCEWS) which is defined as initiatives by a community "to collect information for hazard risk detection, to enable the dissemination of warning messages among at-risk groups, and to facilitate the implementation of emergency plans or responses that can help the community reduce harm or loss from a hazard event".

For Baudoin et al. (2016), CCEWS is a system initiated and conducted by its beneficiaries, grounded in the local level, and a response to the gaps in the "End-to-End" model. For these authors, the common participatory principles to guide CCEWS are the need "to understand local context, integrate local knowledge, and take account of individual motivations when planning and implementing risk management activities" (Baudoin et al., 2016, p. 166).

Based on a gray and scientific literature review about CBEWS on Google scholar electronic search engine, Macherera and Chimbari (2016a) stated that NGOs have nurture the development of CBEWS. The authors identified several examples of CBEWS, as well as analyzed step-by-step guides elaborated by NGOs. The researchers pointed out several gaps regarding EWS' definitions adopted by organizations, such as the lack of specification about the source of the warning, and misunderstandings of *how early* a warning should be issue, since it depends not only on the hazard's characteristics, but on the degree of people's capacities to prepare and cope with risks. Moreover, they stated that definitions often emphasized the need of community participation in the EWS' development, but they do not qualify the extent of engagement or types of participation (Macherera and Chimbari, 2016a).

The next section will discuss about types of participation, considering that despite their different names, these people-centered initiatives have participation as their basic element. Perhaps these diverse types of participation can be used differently in the four-interrelated elements of EWSs, increasing gradually the involvement of people in their designing, implementation and operation.

Participation

Currently social participation is a prominent element in the formulation and implementation of public policies, as it generates greater legitimacy to the process and strengthens governance (Olivato, 2013). It is possible to view participation as a means of mobilizing the subjective knowledge of those affected by climate change and disasters potentially overcoming senses of alienation, apathy or powerlessness.

Social participation refers to the appropriation by individuals of their right to democratic construction of their own destiny. The outcomes depend upon collective organization, providing spaces of discussion within and outside the boundaries of the community for developing strategies for action and the dialog with the public authorities (Tenório and Rozenberg, 1997). Moreover, participatory processes involve overcoming consolidated power relations and ensuring the exercise of citizenship, particularly concerning people in a situation of greater socio-environmental vulnerability (Loureiro and Layrargues, 2013).

To guarantee participatory effectiveness, that is, to produce a favorable outcome, it's essential to ensure the representativeness of various groups of stakeholders, within a transparent decision-making process that provides access to knowledge to all groups involved or affected (Jacobi and Franco, 2011). Santos (2004) points out that participation will only be effective if the community involved is not considered as an object but as subject of the process. According to Dyball et al. (2009), social actors' participation can range from coercion (passive participation, as just representing some group) to co-acting (active participation) (see **Table 1**).

One lesson learned from Hyogo Framework for Action (HFA) is the need to focus on "meaningful participation of relevant stakeholders at appropriate levels" (United Nations International Strategy for Disaster Reduction [UNISDR], 2015, p. 6). Sendai Framework (SFDRR) states that DRR requires an "all – of-society engagement and partnership, empowerment and inclusive, accessible and non-discriminatory participation, paying special attention to people disproportionately affected by disasters, especially the poorest" (United Nations International Strategy for Disaster Reduction [UNISDR], 2015, p. 8).

Concerning specifically community-based disaster risk management (CBDRM), there are several initiatives and forms of participation (Maskrey, 2011), as well as different barriers to citizen engagement, such as gender inequality (Mustafa et al., 2015), lack of transparency, confidence, financing and ownership (Šakić Trogrlić et al., 2017). Preuner et al. (2017), for instance, examines how responsibilities can be shared among the residents, experts, and public authorities during the design and operation of landslide warning systems in Austria. The findings of this case study indicate the need to think carefully about the views, conflicts and different concerns of stakeholders. The authors stated that deliberative planning does not naturally result in sharing responsibilities, once the audience can have different opinions about their own engagement in the control and maintenance of the EWS. However, the deliberative planning was an effective platform for information and for shared ownership in the EWS (Preuner et al., 2017).

TABLE 1 | Types of participation.

Level	Power relationships	Type of participation
Active	Participants set their own agendas. Learnings occur through the negotiation of ways to carry them out actions in collaboration and power shifts depending on the negotiations.	Co-acting
↑	Participants use different forms of knowledge to integrate new understandings. They define common agendas, share responsibilities within existing institutional and social setting and constraints.	Co-creating
	One group takes the initiative and power for enticing other groups to act. They may set jointly issues such as agenda and priorities.	Enticing
	One group (often the government) searches information from different groups, but decides on the final project.	Consulting
	Information is usually just formal, in a one-way flow. It uses technical language and people often feel intimidated to express their views.	Informing
Passive	The will of one group is effectively imposed upon the other. People cannot give opinions nor defend their interests.	Coercing

Source: adapted from Dyball et al. (2009).

Information sharing, crowdsourcing and community disaster mapping can be interesting ways of promoting this deliberative planning in EWS. Indigenous, traditional and science-based knowledge can be connected with technology to contribute to risk detection and monitoring (Baudoin et al., 2016), and to reduce community vulnerability to hazards (Mercer et al., 2010), especially in areas of the world where open source data collection and mobile phone use are increasing (Baudoin et al., 2016). Citizen science approach can a useful way to foster participation in EWS. Next section will discuss models of cooperation in citizen science.

Citizen Science

The term citizen science is new. It arose in the Oxford English Dictionary in 2014. Defined as the engagement of members of the general public in data collection and analysis, usually as part of a collaborative project with professional scientists (Bonney et al., 2016), citizen science has been used in different ways. Some authors consider that it involves a situation in which people use scientific methods to investigate phenomena without any institutional cooperation of scientists (Heiss and Matthes, 2017). Others understand citizen science as a transdisciplinary collaboration between professional scientists and volunteers who are responsible for collecting data and sometimes analyze it, producing an educational outcome (Bonney et al., 2009). However, not all citizen science initiatives realize these two goals to the same degree (Heiss and Matthes, 2017).

Bonney et al. (2016) stated that Oxford's definition does not capture the richness and diversity of citizen science initiatives. For example, it disregards the fact that citizen science supports projects in which audiences participate in tasks beyond collection and analysis of data; projects in which volunteers work not only in teams but also by themselves, with or without the collaboration of scientists; projects that are human-focused rather than ecologically focused; projects that emphasize issues raised not by scientists but by communities; and certainly more types of participatory science that are yet to be imagined. The involvement of social science research projects in this topic, for instance, are still hard to find (Heiss and Matthes, 2017).

The methods and conditions under which citizen science projects can effectively engaging public participants in research remains a key challenge in the field (Bonney et al., 2016). There are at least three models of cooperation in citizen science initiatives (Bonney et al., 2009):

- *contributive* model: volunteers contribute to data collection only;
- *collaborative* model: volunteers get engaged in data collection, analysis and interpretation;
- *co-created projects*: volunteers define the research question and design and are also involved in all phases of the scientific process, including collection, analysis and interpretation of data and information.

These three models of cooperation in citizen science (Bonney et al., 2009) are very similar to three approaches identified by Giordano et al. (2010) regarding the using of local audiences for environmental monitoring, namely: *volunteer monitoring* (citizen involvement in data collection), *collaborative monitoring* (data collection and analysis to help decision making), and *community-based monitoring* (active involvement in the design and operation of the monitoring program) (Giordano et al., 2013). Once EWSs comprise at least other three interrelated axes - risk knowledge, communication and response capability -, it is important to identify and design citizen science initiatives considering contributive, collaborative and/or co-created models, different types of hazards, vulnerabilities and capacities, as well as types of participation according to the variety of audiences.

Disaster risk reduction projects based on citizen science are a challenging area for researching and policymaking. Stone et al. (2014), for example, reported interesting findings about community-based volcano monitoring in Ecuador and showed how observational data provided by volunteers were used by scientists and essential for EWS. This citizen science project around volcano Tungurahua was based on a *collaborative* model where volunteers contribute to data collection, analysis and interpretation. The volunteers "were given basic training from the scientists about what to observe, how to describe phenomena and how to communicate with OVT [Tungurahua Volcano Observatory]" (Stone et al., 2014, p. 7). The identification and analysis of other citizen science initiatives on EWS are an important step to put in place the Unisdr's recommendation of building people-centered EWS (United Nations International Strategy for Disaster Reduction [UNISDR], 2005, 2015). Next section details the methods used in this research.

RESEARCH METHODOLOGY

The objective of this article is to determine elements that bridge citizen science and participatory early warning systems. For doing so, we conducted a literature review that was routed on principles of systematic literature reviews (SLR) and systematic mapping studies (SMS). The former is a means of evaluating and interpreting all the studies available in the literature about research questions, field area, or phenomenon of interest (Kitchenham and Charters, 2007). While, SMS analyzes relevant studies in order to get an overview of an area or theme (Petersen et al., 2008). Reviews that employ this method often aim to answer broader research questions than SLR that is more delimited and bounded. Both methods have their individual and specific set of characteristics and principles that may be not suitable for all types of literature review. That is why we adopted a combination of them, i.e., the rigor and well-defined methodological steps of SLR with the comprehensiveness of SMS. All elements that guided the literature review were established in a previously predetermined protocol, which was defined after three sessions of discussions among the authors. These elements are presented in the next sections.

Research Goal

One of the most important elements when conducting a literature review is the establishment of the research goal. This should comprise not only the description of goal, but also the research scope, as well as the reasons of why the review is relevant and for whom. We thus adopted the goal definition template for supporting "the definition of measurements goals by specifying purpose (what object and why), perspective (what aspect and who), and context characteristics" (Basili, 1994). **Table 2** details the goal of this work using the template.

In regarding the research scope, we also aimed at obtaining only existing primary studies from 2005 to 2018 (Jun) due to the issued date of world-wide disaster risk reduction frameworks; Hyogo in 2005 and Sendai in 2015. Further reason here is to examine the how and if these frameworks motivated and impacted research work in the field. On the basis of these definitions, we establish the following main research questions that this work envisions to answer:

1. RQ1. What are the areas of study?
2. RQ2. What are the types of hazard?
3. RQ3. What are the participatory approaches adopted for supporting EWS?
4. RQ4. What are the models of cooperation in citizen science (Bonney et al., 2009)?
5. RQ5. How existing works cover citizen science projects in EWS?

Search Strategy

On the basis of the research goal, we delineated the search strategy that comprised the selection of sources for obtaining the primary studies, the establishment of inclusion and exclusion criteria and search string, and the definition of the search procedure.

Source Selection

We decided to conduct the literature review on well-known journals in the area of disaster risk management as many venues are not yet indexed in automated digital libraries. Furthermore, we aimed at not only identifying studies that cover the whole extent of the context defined for the research goal, but also to obtaining high-quality articles. The criteria adopted in this work were manifold: (i) the frequency of publications (i.e., the number of publications per period); (ii) research themes covered by the venue (i.e., the themes of interest were those related to the research goal); and (iii) availability of publications (i.e., the article should be available to download). We focused only on journals that published research works in English. **Table 3** shows the selected journals for this literature review.

Most of the selected journals are only focused on themes of interest to this work, such as policies for disaster prevention and mitigation, as well as education efforts for disaster risk reduction. Although some venues motivate a debate on technical areas of disaster analysis like environmental modeling and physical aspects of disaster events, they have been also publishing works that are of particular interest to our work.

TABLE 2 | Goal definition for the literature review.

Analyze	existing literature of disaster risk management
For the aim of	identifying the current state-of-the-art
With respect to	existing efforts that employ participatory information for EWS
From the perspective of	scientists and practitioners
In the context of	disaster risk management

The selection of sources was carried out by a sociologist with expertise in disaster prevention and EWS. His work was developed in collaboration with a computer scientist with experience in conducting systematic literature reviews focused on information systems and collaborative systems for DRM.

Inclusion and Exclusion Criteria

Having selected the sources for analysis, we mapped all situations in which a primary study would be selected to our literature review. The study selection was then summarized in a set of filtering criteria, i.e., inclusion and exclusion criteria. The primary study is included if: (1) it proposes approaches to use citizen data in the context of EWS; or (2) it reports both scientific and practical experiences of participatory early warning systems. In contrast, a study is excluded in the following situations: (1) it is not written in English; (2) it is not available online; (3) it is duplicated; (4) it is not related to early warning systems; (5) it is not related to citizen science, or participatory data; (6) it is a previous version of a more complete study about the same research; (7) it is an editorial, position paper, keynote, opinion paper, tutorial, poster or panel; (8) it is a secondary study (e.g., reviews, surveys, and SLRs). The first two authors of this work were responsible for establishing and defining these criteria.

Search String

Since this article aims at investigating the linking of citizen science and participatory early warning systems, we selected four main keywords, "citizen science," "early warning systems," "natural hazard" and "social science." These were then associated with their related synonyms. The final search string is: ("participatory" OR "citizen science" OR "people-centered" OR "community-based") AND ("early warning system") AND ("natural hazard" OR "disaster management" OR "disaster risk reduction") AND ("social science").

For evaluating and refining the defined elements, the first two authors conducted a pilot study that was focused on analyzing the title, abstract, and keywords of articles returned in the first page of a search in the Scopus. This search was carried out utilizing the search string, while the selection of studies employed the inclusion and exclusion criteria. After the pilot study, both authors have agreed that no additional modifications would be necessary in the established criteria or in the search string.

Data Extraction

With the aim of answering the research questions proposed in this work, a set of items were defined to be extracted from the selected primary studies. **Table 4** presents the extracted items.

For extracting data, each selected study was read in full by one of the authors, which was also responsible for identifying and extracting the data. Only items I10 and I11 had predetermined alternatives to selecting, i.e., "co-created projects, collaborative model, contributive model, no, or others" for I10 and "Co-acting, co-creating, coercing, consulting, enticing, or informing" for I11. The remaining items were all open-text fields. The I10

TABLE 3 | Selected journals for this literature review.

Journal	Link	Creation Year	2017 JCR Impact Factor
Disasters	https://onlinelibrary.wiley.com/journal/14677717	1977	1.596
Natural Hazards	https://link.springer.com/journal/11069	1989	1.901
Disaster Prevention and Management	https://www.emeraldinsight.com/journal/dpm	1992	1.060
Environmental Hazards	https://www.tandfonline.com/toc/tenh20/	1999	1,220
Natural Hazards and Earth System Science	https://www.natural-hazards-and-earth-system-sciences.net/	2001	2.281
Journal of Disaster Risk Studies (Jamba)	https://jamba.org.za/index.php/jamba	2006	Not ranked
International Journal of Disaster Risk Science	https://www.springer.com/earth+sciences+and+geography/natural+hazards/journal/13753	2010	2.225
International Journal of Disaster Risk Reduction	https://www.sciencedirect.com/journal/international-journal-of-disaster-risk-reduction	2012	1.968
Resilience	https://www.tandfonline.com/loi/resi20	2013	Not ranked

TABLE 4 | Extracted items.

Item	Title
I1	Title
I2	Author (s)
I3	Year
I4	Journal
I5	Abstract
I6	Affiliation (s)
I7	Study area
I8	Type of hazard (s)
I9	Citizen science
I10	Models of cooperation
I11	Type of participation

predetermined alternatives were based on classification proposed by Bonney et al. (2009), detailed previously in theoretical background. The I11 alternatives were also explained in the same section and were based on Dyball et al. (2009).

Search Procedure

Based on the inclusion and exclusion criteria, search string, and data extraction, we defined a search procedure for selecting primary studies and later answering the research questions. This procedure comprises three sequential phases: (a) *searching studies* on selected journals (Phase 1); (b) *selecting studies* based on inclusion and exclusion criteria (Phase 2); (c) *analyzing and extracting relevant information* of selected studies (Phase 3).

To start with, the search string was applied in each of the selected source listed in **Table 3**, searching the keywords and their synonyms in the title, abstract and keywords of primary studies. As mentioned previously, we considered only those studies published between 2005 and 2018 (June). Furthermore, in only one case, we had to customize the string before applying it. Environmental Hazard journal requires the inclusion of specific metadata[1]. All primary studies returned by the searching process were downloaded and imported into the SLR management tool. This work adopted as a tool, the Parsifal[2], which supports the conducting of SLR.

During the second phase, the set of imported studies was analyzed taking as a basis the inclusion and exclusion criteria. Here, we still rely only on the title, abstract and keywords of the studies. When necessary, the introduction and conclusion of a study were also read and analyzed. As a result, a list containing only those studies considered potentially relevant would be generated.

Finally, all studies selected in the previous phase were read in full-text and still analyzed based on the inclusion and exclusion criteria. This analysis was important as the title and abstract of some studies may not reflect clearly the developed work so they should not be considered for data extraction. This phase also included the extraction of all data relevant to answer the proposed research questions. **Figure 1** depicts the search procedure with a number of studies per phase.

From an initial set of 408 studies, a total of 125 were selected for data extraction; this represents almost 1/3 of studies, or 30,64%. During data extraction, other 32 articles were excluded. At the end, 93 studies (22,79%) were selected for our final analysis. It is also worthwhile to mention that we did not have duplicated studies as we conducted the review on individual journal instead of indexed/automated databases.

RESULTS

This section first details the characterization of the selected studies that comprises the number of studies per year, per selected source, and per country of affiliations. Following, it presents the study results of this literature review focusing on those relevant to answer the research questions. The list of selected studies is available as a **Supplementary Material**.

[1] [[All: "participatory"] OR [All: "citizen]] AND [[All: science"] OR [All: "people-centered"] OR [All: "community-based"]] AND [All: "early warning system"] AND [All: "natural] AND [[All: hazard"] OR [All: "disaster]] AND [[All: management"] OR [All: "disaster]] AND [All: risk reduction"] AND [All: "social science"] AND [in Journal: Environmental Hazards] AND [Publication Date: (01/01/2005 TO 06/30/2018)].

[2] https://parsif.al/about/

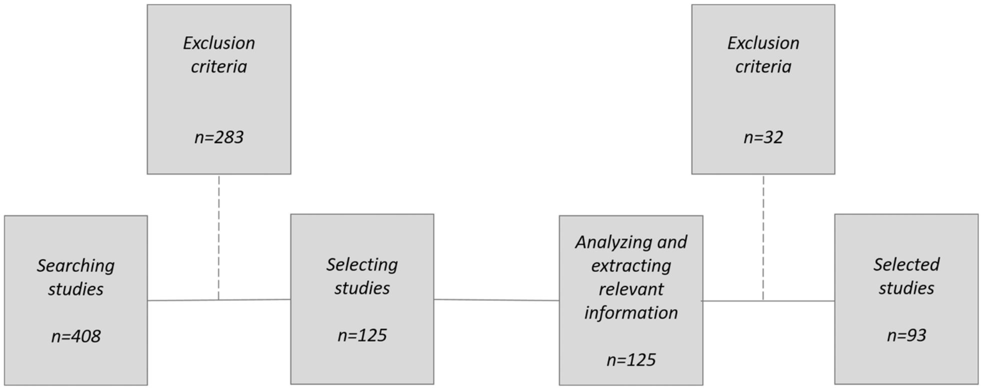

FIGURE 1 | Search procedure.

Studies Characterization

Our research reveals an increasing tendency of published articles about EWS during 2005–2018 (**Figure 2**). Interestingly, the two tipping points in this whole period occurred in 2010 (9 articles) and in 2016 (15 articles). Maybe the Hyogo Framework for Action (HFA), published in 2005, and the Sendai Framework for DRR (SFDRR), adopted in 2015, have influenced research agenda, since Unisdr provided substantial recommendations regarding EWS (2005; 2006; 2009; 2015). Even the creation of new journals covering disaster risk management issues would have influenced these numbers.

Four of the nine journals analyzed in this study (**Table 3**) were created after HFA and have important percentage of the selected publications (**Figure 3**), as well as are ranked with high JRC Impact Factor. For instance, International Journal of Disaster Risk Reduction- IJDRR (created in 2012 and JCR Impact Factor = 1.968) has similar percentage of selected studies (5,38%) when compared to Disaster Prevention and Management-DPM (created in 1992 and JCR Impact Factor = 1.060), which has 7,53% of selected studies in this paper (**Figure 3**). International Journal of Disaster Risk Science-IJDRS (created in 2010 and JCR Impact Factor = 2.225) has 12,9% of selected studies. Three journals created before HFA represent 67,74% of selected publications (Natural Hazards = 29,03%; Environmental Hazards = 21,51%; and Disasters = 17,2%) (**Figure 3**). This paper does not want to explain the reasons of these differences - which can be diverse, such as open access policy, aims and scope of each journal etc. Our purpose is to show briefly the landscape of this field to understand how citizen science can be inserted in participatory early warning initiatives.

Other important aspect for planning the expansion of research networks and capacity building of human resources in EWS agenda is the author's affiliation per country (**Figure 4**). Of the selected articles, there are authors and co-authors affiliated in organizations of 29 countries (Europe: 12; Asia: 9; Africa: 4; Americas: 2; Oceania: 2). 49,46% (46) have authors and

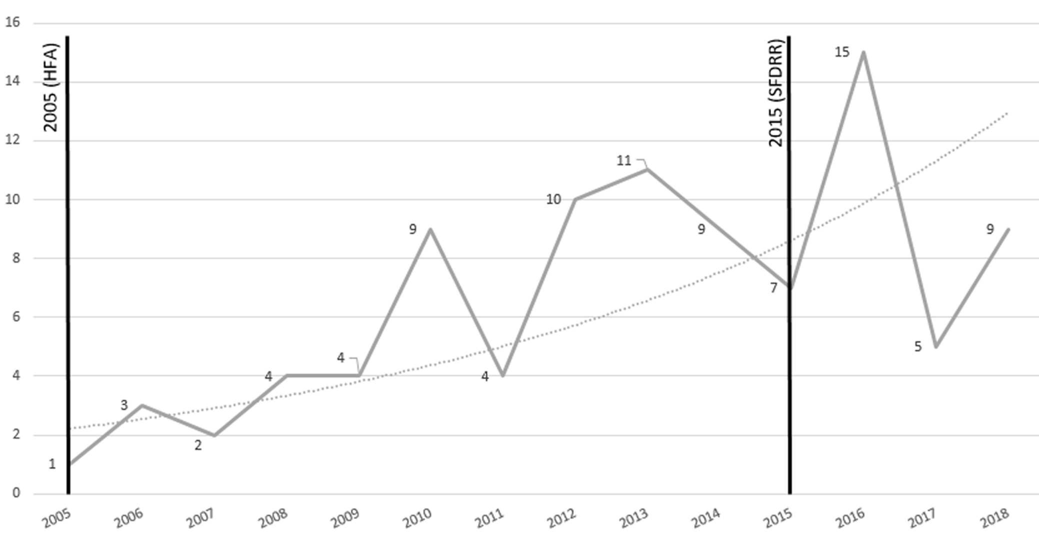

FIGURE 2 | Number of selected studies per year.

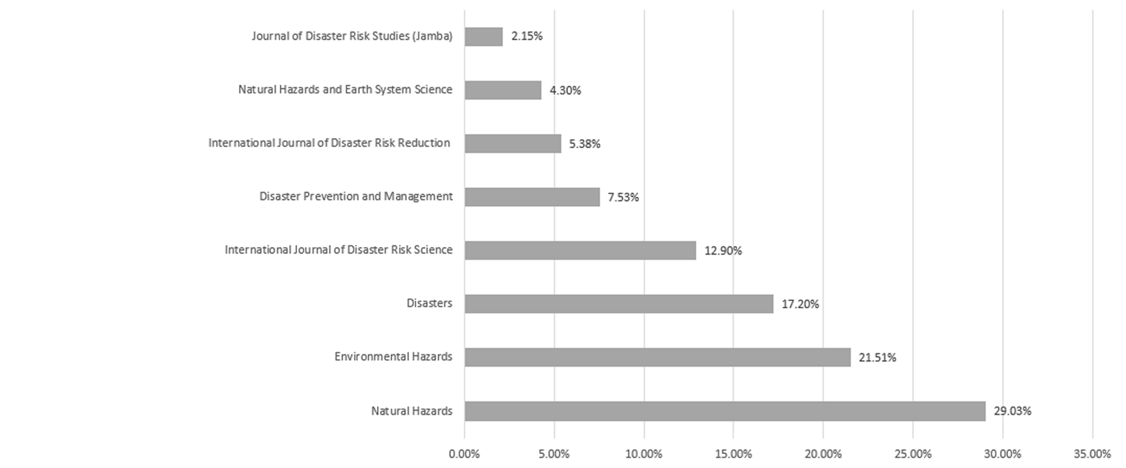

FIGURE 3 | Percentage of selected studies per source.

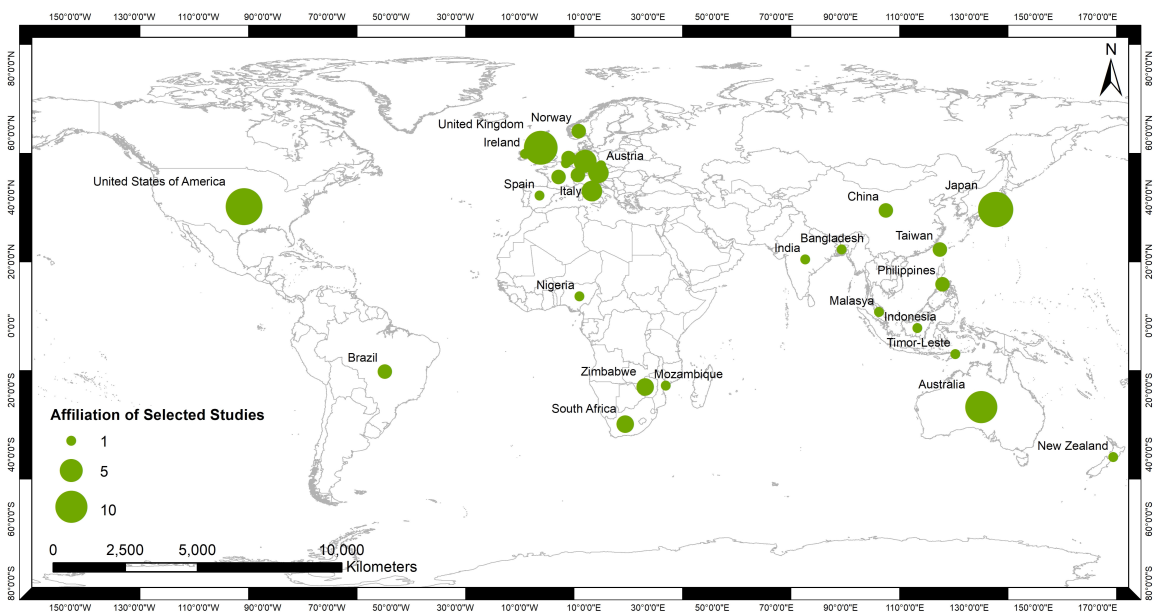

FIGURE 4 | Selected studies per country of affiliation.

co-authors affiliated in organizations from United States (13 articles), Japan (12 articles), United Kingdom (11 articles) and Australia (10 articles). Organizations from Europe are represented in 38,7% (36) of the 93 papers selected, while organizations from African countries are in 8,6% (8) of them. It is important to highlight that there are researchers and/or practitioners affiliated in more than one organization, and this multi-affiliation was not excluded. We also consider Taiwan as a country to respect the author's opinion.

Characterization per Areas of Study and Types of Hazards

In regarding to the first research question (RQ1) proposed in this paper – about the studied areas – 43 countries were analyzed in the 93 selected papers (**Figure 5**) -only in 5 papers (5,37%) were not possible to identify the country that was studied, because articles focused on regional scope, and/or prioritized consultations with stakeholders from different countries around the world, and/or gathered data and information through participatory workshops during international conference on DRR. This represents a high diversity of study areas in which the research works have been developed. It is also important to point out that many studies did comparative analysis involving two or more countries. Asian countries, for instance, were studied in 55,91% (52) of these 93 studies. By no surprise, the first five study areas were all countries affected by hazardous events in the last years, 2009 Earthquake in Indonesia, 2012 Typhoon in the United States, 2011 Tsunami

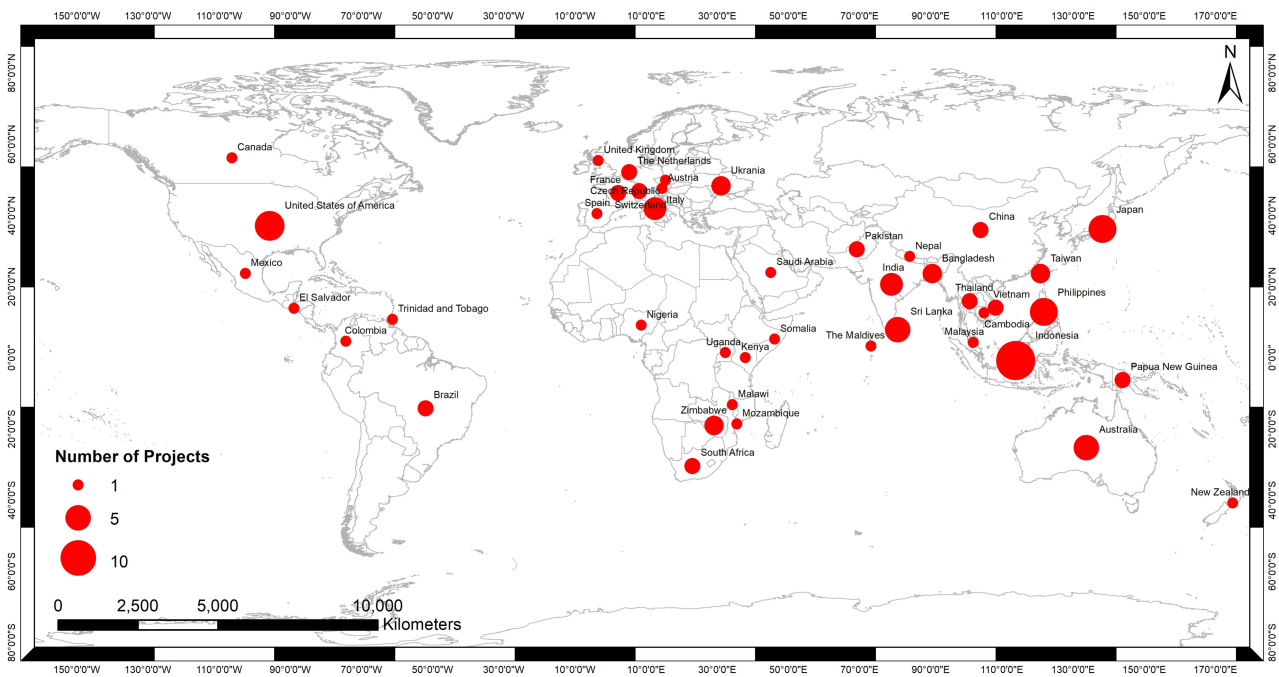

FIGURE 5 | Distribution of selected studies per study area.

in Japan, 2013 Typhoon in the Philippines and 2015 Floods in Sri Lanka.

Other important element of this characterization is the type of hazard in the selected publications. Floods represent the more frequent hazard studied during the period 2005–2018 (**Figure 6**) and the higher percentage (29%) of the selected studies, followed by tsunamis (13%) and droughts (9%) and tornadoes (9%) (**Figure 7**). Other interesting finding is the diversity of hazards discussed, from landslide to public health threats. In 2016, there were selected articles discussing EWS for different types of hazards (multihazard, floods, tornado, tsunami, earthquake, wildfire, drought, malaria, and landslide) (**Figure 6**).

Characterization per Types of Participatory Approaches and Models of Cooperation in Citizen Science

In regarding to the types of participation, it is important to point out that during the searching studies we identified 408 results. 283 studies (69,36%) were excluded because they were not related with early warning system or participatory data (Phase 1, **Figure 8**). 125 papers were evaluated during data extraction and analysis (Phase 3, **Figure 8**) and another 32 studies were excluded, mainly because they were not related with participatory data (56,25%). In general, these excluded studies used data to compose indexes of vulnerability, exposure, resilience, but this data is not collected with people.

Of 93 studies selected, the majority (84,95%) reported participatory experiences in a consultative way, i.e., through surveys, interviews, questionnaires. These studies evaluated opinions of different stakeholders regarding EWS, evacuation behavior, risk perception about warning information etc. The findings indicate that 15,05% (14) of selected studies (93) dealt with citizen science (**Figure 9**), through data collection and analysis. The model of cooperation (Bonney et al., 2009) most used was collaborative (11 articles), followed by contributive (2) and co-created (1).

DISCUSSION

In the days following the Tsunami of 26 December 2004, the Secretary-General of United Nations, Mr. Kofi A. Annan (in memoriam), called for the development of a global EWS for all natural hazards and communities, and a global survey was launched to assess the capacities, gaps and opportunities (United Nations International Strategy for Disaster Reduction [UNISDR], 2006b). One of the most important issue highlighted by the Secretary-General was the need of participatory approaches in EWS and, almost 15 years later, this paper provides evidence that further investigation is still necessary. From an initial set of 408 studies published in well-known journals in the area of disaster risk management (DRM), only 14 (3,43%) articles were related to citizen science and P-EWS, which indeed indicate that much effort is needed to disseminate what is citizen science and how it can be mainstreamed in DRM field.

Hence, this paper contributes to this debate on P-EWS by (1) linking it to citizen science models of cooperation (Bonney et al., 2009), as well as by (2) identifying

	Food security	Multi-Hazard	Volcano	Flood	Tornado	Tsunami	Earthquake	Influeza A	Wildfire	Drought	Malaria	Not Defined	Debris-Flow	Landslide
2005	1													
2006		1		1		1								
2007				2										
2008		1		1		2								
2009		1				1				2				
2010				1	3	1	2		1					1
2011				2		1	1							
2012		2	2	3	2		1							
2013		2		4						3				2
2014		3	1	2		1				1			1	
2015		1		2	1	1	1			1				
2016		1		4	1	1	1		1	1	1	3		1
2017				3		2								
2018		1		2	1	1		1	1			1		1

FIGURE 6 | Distribution of selected studies per type of hazard, per year.

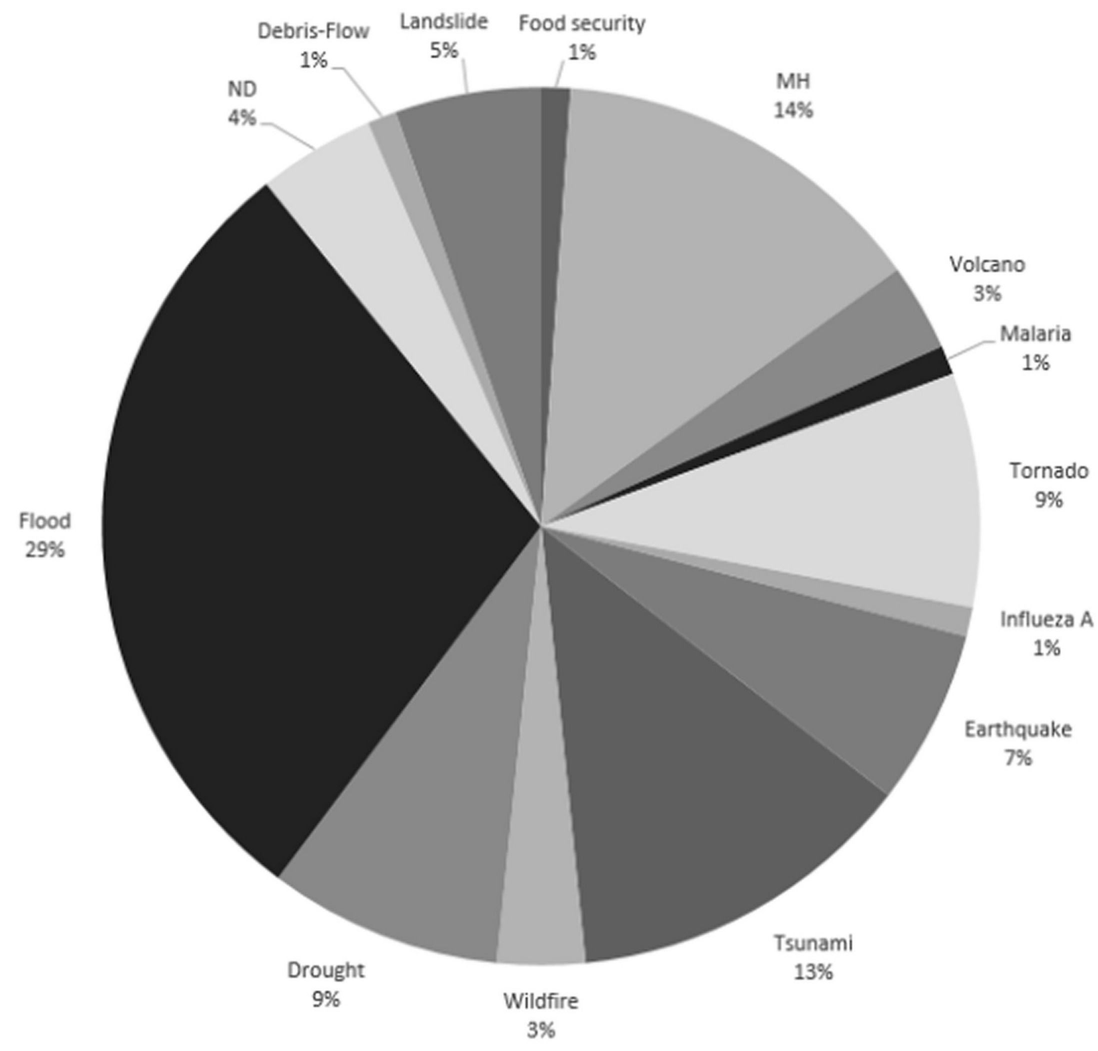

FIGURE 7 | Distribution of selected studies per type of hazard.

how existing works cover citizen science projects and P-EWS. These contributions have been done through the identification of three key issues that were raised from the literature review and then the establishment of a framework for enhancing reflexivity about P-EWS and citizen science.

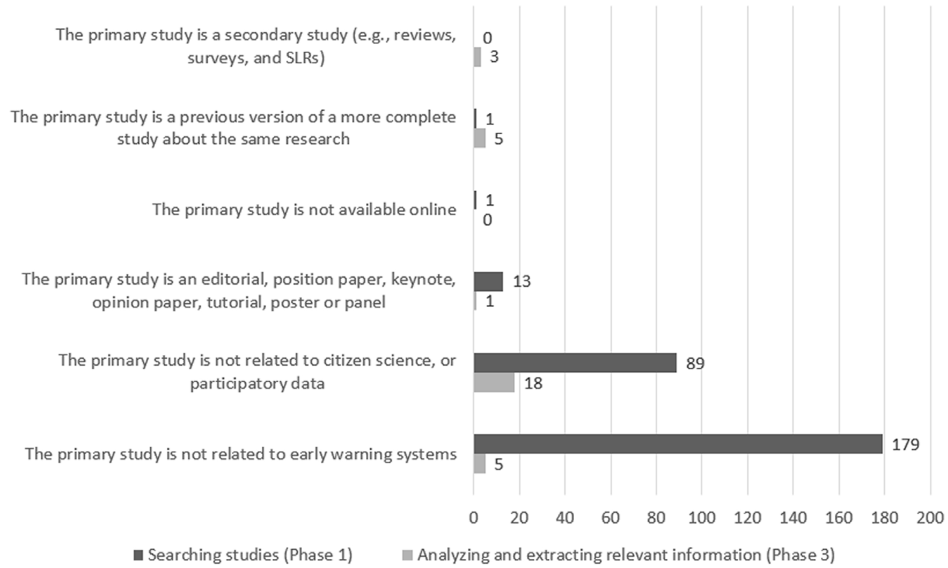

FIGURE 8 | Number of excluded studies per criteria, per phase.

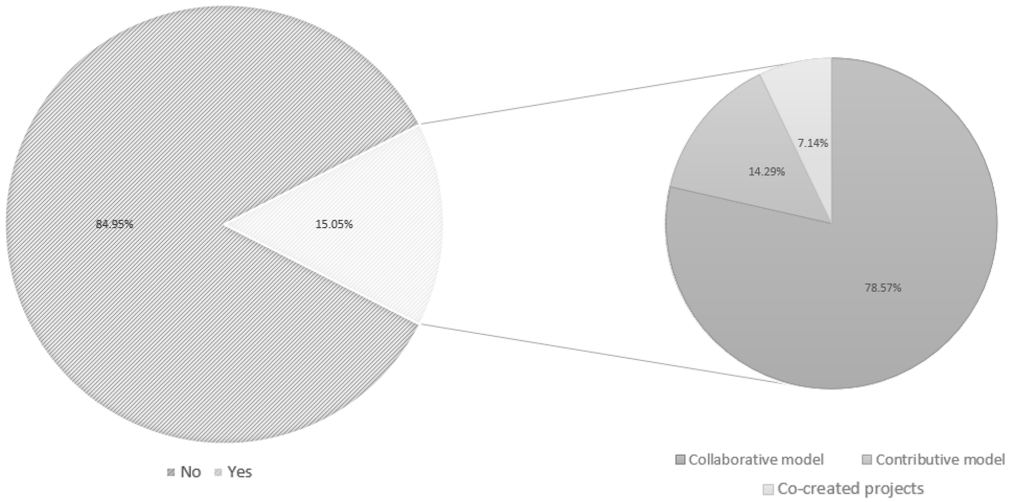

FIGURE 9 | Distribution of selected studies on citizen science projects and per model of cooperation.

DRM Actions Should Recognize the Importance and Usefulness of Citizen Data

Analyzing the case of Pakistan, Mustafa et al. (2015) stated that there is little room in the data-acquisition protocols of the Pakistan Meteorological Department (PMD) to include citizen or non-governmental based data collection. This is interesting as many meteorological services around the world have been educating the public about meteorological data collection. The authors stated that "the very basic principle of involving citizens in meteorological data collection and processing would be one important step toward not only expanding the data network but also improving public awareness and risk knowledge" (Mustafa et al., 2015, p. 15).

Another interesting case was reported in Malawi. Šakić Trogrlić et al. (2017) noted the installation of water level and rainfall gauges as a part of community-based EWS, where communities are trained to operate equipment, communicate warning messages, and also act in extensive reafforestation programs. According to the authors, there are practical EWS participatory experiences reporting that rainfall data collected by communities are not being stored by the Meteorological Services (Šakić Trogrlić et al., 2017). In the same manner, Horita et al. (2018), through a qualitative analysis of decision-making in monitoring control room, showed the importance of data from the communities as a supplementary source of information.

This is more relevant and important when official data sources are insufficient, non-existent, or not well calibrated, which thus may lead to "operators deciding 'in the dark' without knowing the 'real' situation in the area; this occasionally may lead to devastating consequences due to a wrong decision" (Horita et al., 2018, p. 29).

Not only policymakers, scientists and practitioners can be unaware of what is citizen science, but sometimes citizens do not know that an EWS exists or even they do not consider why they should participate in EWS. Through participatory rural appraisal techniques that combined focused group discussions, Nguyen et al. (2009) stated that 86% of community members of Svay Rieng province, Cambodia, believed that they personally had no role to play in the dissemination of early warning for droughts. In another pilot study, but at Lake Trasimeno, Italy, Giordano et al. (2013) stated that local residents perceived institutional monitoring and management actors as having a central role and have not considered themselves as potential sources of knowledge to develop a community-based strategy to monitoring droughts.

But there are places where formal EWS are absent or largely malfunctioning, and citizen engagement is not a matter of choice. During Typhoon Morakot in Taiwan, several residents of mountainous villages in Kaohsiung city had to rely on their own capacities to evacuate from debris-flow prone areas. Only 13.8% of the residents received institutional (official) alerts, whereas 86.2% of households had to be confident of their knowledge and impressions to identify the onset of debris-flows - 73% had no experience in disaster education or previous disaster (Luo et al., 2014). Beyond the EWS failures due to damaged communication infrastructures, many village mayors re-assessed alerts from higher authorities and did not forward warnings and evacuation orders to the people. According to Luo et al. (2014), the crucial point is that the current EWS system in Taiwan does not permit the engagement of people, especially in CBDRM initiatives.

DRM Should Be More Grounded in Citizen Science, Interdisciplinary and Transdisciplinary Works

We identified that 84.95% of selected articles reported EWS experiences in a consultative way (**Figure 9**), searching occasional information from different groups through surveys, interviews etc. New strategies are necessary to promote the use of participatory methodologies of *co-producing of data, information and knowledge that matter for citizens* and practitioners. There is a richness of participatory methods and tools to enhance the development of CBDRM (Maskrey, 2011). Interdisciplinary methods, such as developed by social volcanology (Donovan et al., 2012), permit to understanding how different cultures influence the local community actions during eruptions. Using ethnography to analyze the EWS functioning during 2006 eruption at Mt Merapi, Indonesia, Donovan et al. (2012) stated that local people refused to evacuate because they had not received the traditional warnings which include forest animals descending from the summit regions into the villages, an increase in rock falls, a change in plume direction, dreams or premonitions. The authors mapped these and other information and included them in GIS platform to subsidize EWS activities. Diverse types of indigenous EWS were reported in Philippines (Hilhorst et al., 2015), India (Panda, 2016), Zimbabwe (Macherera and Chimbari, 2016b). There are important actions to bridge indigenous EWS and citizen science, such as the inclusion of social scientists in interdisciplinary and transdisciplinary EWS' teams, the promotion of researches about cultural norms and traditional forms of knowledge, and the identification of types of scientific and traditional data that can facilitate communication and capacity building according to types of hazards and vulnerabilities. For instance, hydrology and water management have been dialoguing about methods, technologies, experiences and types of data (precipitation, water quality, water use etc.) that can be collected, analyzed and shared in different levels of engagement in citizen science projects (Buytaert et al., 2014).

In Zimbabwe, an interesting community-based malaria EWS framework was developed to integrate indigenous knowledge and the conventional health system (Macherera and Chimbari, 2016b). Using participatory rural appraisals and workshops, communities made a trend analysis of malaria from 1970 to 2011 and that of temperature and rainfall from 1960 to 2011. To foster their risk knowledge and monitoring capacity, they were asked to construct malaria calendars with its causes and the season of occurrence. During focus group discussions (FGDs), the indicators used by the community to predict the occurrence of malaria were documented. FGDs indicated that the behavior of lions and elephant can be used as indicators for malaria. Communities stated that whether elephants or lions pass through the villages at night during the month of September, it means that the coming malaria season is going to be bad (Macherera and Chimbari, 2016b). After documenting this and other indicators (wind patterns, direction and variation etc.), participants agreed who would be the volunteers willing to carry out observations and monitoring. The group of observers also included women and caregivers at the household level. These FGDs also planned the third axis of EWS – risk communication. They determined that communication of the indicators should be two directional – from the observers to the general population and also from population to the observers. The warning should be communicated to the people through the village health workers, the observers and the health workers. This example of citizen science initiative fits into the collaborative model of cooperation because volunteers get engaged in data collection, analysis and interpretation (Bonney et al., 2009).

Other interesting case about landslide P-EWS was reported in Sri Lanka. The pilot project in the Matale district started in 2009 and engaged residents of landslide-prone areas in educational programs, training and evacuation drills. They were trained to daily monitoring of rainfall data in portable fiberglass rain gauges and educated on how to communicate data to their neighborhood (Baudoin et al., 2016). The rainfall thresholds were marked in the rain gauges and colors (green, yellow, and red) were used to differentiate important measures and actions to be taken. For instance, the red threshold implies evacuation.

This P-EWS experienced an emergency situation in October and November 2010, and "121 families used this method to evacuate to safer places during landslides" (Baudoin et al., 2016, p. 169).

Heterogeneous Aspects of Citizenship and Science Will Demand Supplementary Actions in DRM

One crucial element that needs further research is *how the different groups can be involved in P-EWS and citizen science initiatives according to the diverse cultures, political contexts and risk scenarios* they face. Some of the selected studies pointed out the importance of taking into account gender issues. As stated previously in theoretical background, gender is related to the political, economic, social and cultural constructed roles and responsibilities imputed to women and men, girls, boys and members of sexual and gender minorities, which are inseparable from power relations, change over time, are context- and history-specific, determining social spaces and (non)availability of opportunities – influencing the vulnerability and ability to prepare, respond and recover (Mustafa et al., 2015).

Discussing how to gendering flood EWS in Pakistan, Mustafa et al. (2015) shared important findings about citizen engagement. The authors stated that culturally appropriate and gender-specific EWSs need to go beyond blaring out a siren and tailoring risk messages. Afghan Abadi is home to around 5000 families, including ethnic Pashtuns from different provinces in Pakistan and refugees from Afghanistan settled for the last 30 years. While men are employed in the local market or as daily wage laborers, women's mobility is excessively limited due to a stricter understanding of purdah. As put by one respondent interviewed by Mustafa et al. (2015, p. 12–13): "We are not allowed to go outside of our houses. We know about flood hazard from our men. There are announcements in the mosques but loud speakers do not work due to absence of electricity, we could not hear that warning (...) Even during floods women are not allowed to go outside the homes without the permission of the males. We find safe places inside the home to save ourselves. We cannot move anywhere without the permission of our husbands and for the fear of punishment". *The impact of gendered norms on decision-making in EWS needs to be considered in the design of citizen initiatives*. Important findings about EWS performance were reported during floods in Indonesia (Mulyasari and Shaw, 2013), wildfire in Australia (Tyler and Fairbrother, 2018) and landslides in Colombia (Coles and Quintero-Angel, 2018).

In Bandung, Indonesia, Women Welfare Associations (WWAs) have been mobilizing the community to engage in EWS. During the 2009–2010 floods, WWA was involved in monitoring water levels, disseminating risk information to communities through FM radio stations and newspapers, coordinating relief efforts etc (Mulyasari and Shaw, 2013). Another participatory EWS experience involving women was reported in Manizales, Colombia. The program "Guardians of the Slope" hires female heads of household to communicate landslide risk to the residents and to maintain landslide-prevention infrastructure. The women guardians are also responsible for conducting door-to-door educational activities and also to share their knowledge with children and youth in school meetings (Coles and Quintero-Angel, 2018).

Other crucial bridging point is *considering age groups and intergenerational capacities in tailoring participatory EWS*, including children (Muzenda-Mudavanhu et al., 2016), youth (Fernandez and Shaw, 2013; Cumiskey et al., 2015; Marchezini et al., 2017) and elderly (Paveglio et al., 2010). Some studies have produced a series of recommendations for enhancing youth participation (Fernandez and Shaw, 2013; Cumiskey et al., 2015), as well as participatory methodologies to work with citizen science in the four elements of EWS with the help of school curricula (Marchezini et al., 2017). Despite of taking into account the vulnerabilities of these groups and developing pathways for including them in EWS, *further research is necessary to consider other groups*, such as migrants and refugees, because migrants represent 14% of global population and almost 200 million people were forced to move as consequence of disaster from 2009 to 2015 (Internal Displacement Monitoring Centre [IDMC], 2015; Guadagno, 2016). Human mobility refers to the population movements – voluntary or forced, assisted or spontaneous, long- or short-distance, long- or short-term (Guadagno, 2016). According to Guadagno (2016), it is important to include migrants in EWS, fostering appropriate structures and procedures, as well as collecting data disaggregated by mobility status and other characteristics (gender, age, ethnicity etc.). For instance, Stokoe (2016) highlighted the importance of putting people at the center of United States's tornado warnings and asked how to include the 11.2 million illegal immigrants in the EWS.

Framework for Enhancing Reflexivity About PEWS and Citizen Science

Based on the literature review on participatory EWS and citizen science, we provide a framework for enhancing stakeholders' reflexivity about EWS (**Figure 10**). Reflexivity means the constantly monitoring, reexamination and reformation of social practices in the light of incoming information about them, altering their character (Giddens, 1990). For Giddens (1990, p. 83), "the nature of modern institutions is deeply bound up with the mechanisms of trust in abstract systems, especially trust in expert systems." EWSs are abstract systems that deal with uncertainties and fail, as exemplified in 2004 tsunami in Asia and Africa (Kelman, 2006). To recover trust in EWS is essential to think about the types of participation (co-acting, co-creating, enticing, consulting, coercing, and informing) (**Figure 10**). Co-acting and co-creation permit that participants share their knowledge, set their agendas and negotiate ways, defining roles and responsibilities. Participatory approaches, such as Views from the Frontline methods (Global Network of Civil Society Organizations for Disaster Reduction, 2013; Gibson and Wisner, 2016) give voice to people and can offer important insights for designing EWS for multiple hazards and vulnerabilities. These types of participation open opportunities for models of cooperation in citizen science, such as contributive, collaborative or co-created projects (**Figure 10**). These types of cooperation can involve different stakeholders,

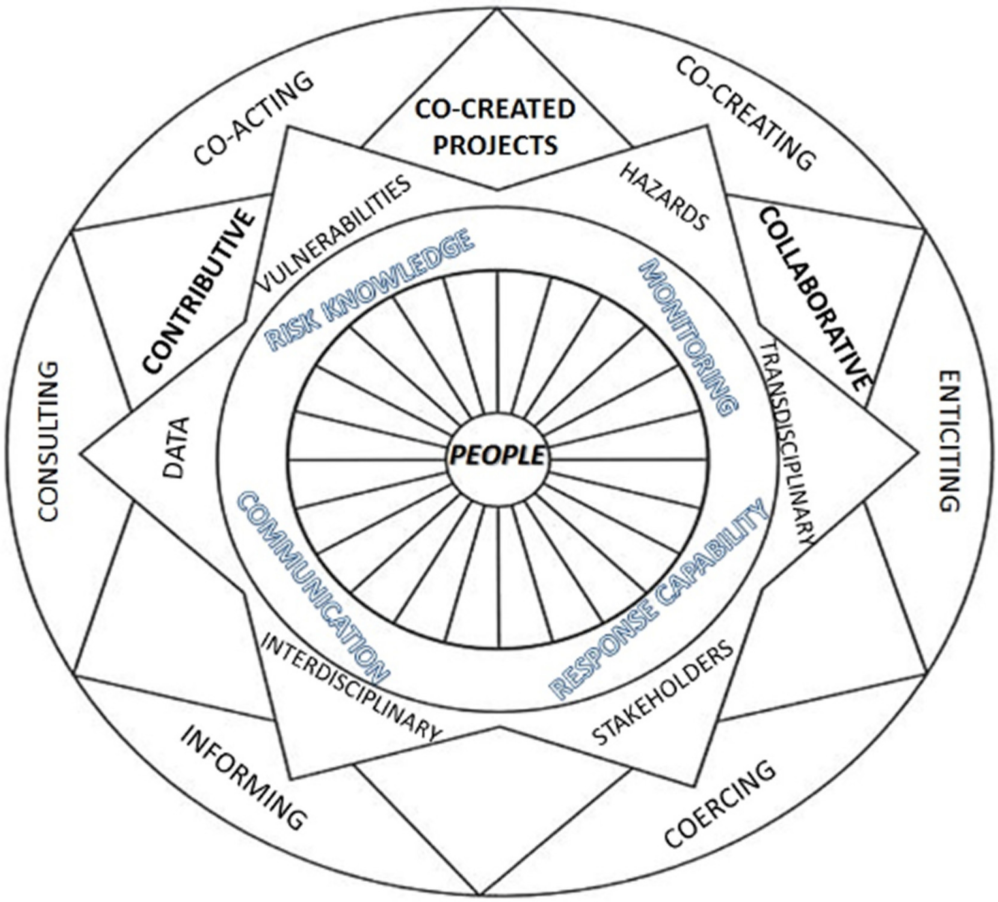

FIGURE 10 | Framework for enhancing reflexivity about PEWS and citizen science. Source: the authors.

fostering transdisciplinary dialogs among experts, practitioners, communities, policymakers, as well as interdisciplinary methods for data collection and analysis, building integrated research, such as provided by Forensic Investigations of Disasters' method (Oliver-Smith et al., 2016). These approaches and methods can involve each of four interconnected elements of EWS - risk knowledge, monitoring, communication and response capability. This reflexivity process should be people-centered, taking into account gender, age, ethnic, minorities and other important aspects of social life (Kelman and Glantz, 2014; Mustafa et al., 2015). Mainstreaming EWS to consider different groups and sectors (Zia and Wagner, 2015) is a challenge that DRR community will face, and maybe citizen science can offer pathways to implement new initiatives among citizens-practitioners-scientists.

Limitations

Although this work provided a valuable framework for bridging citizen science and P-EWS, some limitations should be acknowledged. To start with, articles published in further journals should be reviewed in order to cover the whole extent of the literature in the theme. The review conducted on well-known journals in DRM aimed at raising the most valuable articles, but some other efforts may be left out. In the same manner, these reviews should also cover conferences in the themes; for example, International Conference on Disaster Response and Management (ICDRM), and Early Warning Conference promoted by Unisdr. Another potential limitation of this work might be that inclusion and exclusion criteria left relevant studies out of the final set of primary studies. The activities to mitigate this issue were the following: (1) a pilot study has been conducted in order to refine both these criteria and search string and (2) as several phases of the research methodology have been conducted by different researchers, a discussion session was conducted with the aim of aligning the elements of methodology (e.g., search strategy, inclusion and exclusion criteria, and data extraction form). The later was also particularly valuable and relevant to reduce the subjectivity of the analysis.

CONCLUSION

This paper has carried out a literature review of 93 selected articles which findings can support future actions related to

P-EWS and citizen science. Study findings showed that there is a concentration of studies on Asian countries (55,9% of the selected studies), as well as the concentration of scientific production in organizations in developed countries (49,46% of selected articles have authors and co-authors affiliated in organizations from United States, Japan, United Kingdom, and Australia). Furthermore, results of this literature review provided evidence of the predominance of floods as the main hazard (29% of selected studies), and the low popularity of citizen science in well-known journals in the field of DRM. Based on these findings, it is important to enhance scientific meetings, capacity building and funding to foster research in less represented countries, building local and national capacity in research, policy-making and citizen engagement in P-EWS.

Moreover, it is essential to promote the use of participatory methodologies and to create mechanisms to monitor the implementation of P-EWS, taking into account the long-term effort involved in this type of initiative. The promotion of new agreements between donors and funding agencies to redesign the duration of the EWS projects and the types of scientific deliverables – less articles, more connection with local demands – could drive more implementation of P-EWS. Citizen science research programs on this issue can create new opportunities to connect people to think about disaster risk reduction and global environmental change.

AUTHOR CONTRIBUTIONS

VM and FH led the conception and design of the paper. VM selected the studies. VM, FH, PM, RT, MT-R, and DO analyzed and extracted relevant information from the selected studies. VM led the description and discussion of the case studies. VM, FH, PM, RT, MT-R, and DO contributed to the development of ideas and to the interdisciplinary reflection process.

FUNDING

RT, PM, and DO acknowledge the Brazilian Council for Scientific and Technological Development (CNPq) for their research scholarships. MT-R acknowledges support from the Coordination for the Improvement of Higher Education Personnel (CAPES) for his Ph.D. scholarship. FH would like to express thanks for the financial support provided by CAPES (Grant No. 88887.091744/2014-01).

ACKNOWLEDGMENTS

The authors are grateful to the Editors, Dr. Jonathan D. Paul, Dr. David M. Hannah and Dr. Wei Lu, and the reviewers for their helpful suggestions.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2018.00184/full#supplementary-material

REFERENCES

Aitsi-Selmi, A., Murray, V., Wannous, C., Dickinson, C., Johnston, D., Kawasaki, A., et al. (2016). Reflections on a science and technology agenda for 21st century disaster risk reduction. *Int. J. Disast. Risk Sci.* 7, 1–29. doi: 10.1007/s13753-016-0081-x

Basher, R. (2006). Global early warning systems for natural hazards: systematic and people-centred. *Philos. Trans. A Math. Phys. Eng. Sci.* 364, 2167–2182. doi: 10.1098/rsta.2006.1819

Basili, V. (1994). GQM approach has evolved to include models. *IEEE Softw.* 11, 1–8.

Baudoin, M. A., Henly-Shepard, S., Fernando, N., Sitati, A., and Zommers, Z. (2016). From top-down to community-centric approaches to early warning systems: exploring pathways to improve disaster risk reduction through community participation. *Int. J. Disast. Risk Sci.* 7, 163–174. doi: 10.1007/s13753-016-0085-6

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., et al. (2009). *A CAISE Inquiry Group Report*. Available at: http://files.eric.ed.gov/fulltext/ED519688.pdf [accessed May 2, 2018].

Bonney, R., Cooper, C. B., and Ballard, H. (2016). The theory and practice of citizen science: launching a new journal. *Citizen Sci. Theory Pract.* 1:1. doi: 10.5334/cstp.65

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Front. Earth Sci.* 2:26. doi: 10.3389/feart.2014.00026

Coles, A. R., and Quintero-Angel, M. (2018). From silence to resilience: prospects and limitations for incorporating non-expert knowledge into hazard management. *Environ. Hazards* 17, 128–145. doi: 10.1080/17477891.2017.1382319

Cumiskey, L., Hoang, T., Suzuki, S., Pettigrew, C., and Herrgard, M. M. (2015). Youth participation at the third UN world conference on disaster risk reduction. *Int. J. Disast. Risk Sci.* 6, 150–163. doi: 10.1007/s13753-015-0054-5

Donovan, K., Suryanto, A., and Utami, P. (2012). Mapping cultural vulnerability in volcanic regions: the practical application of social volcanology at Mt Merapi. Indonesia. *Environ. Hazards* 11, 303–323. doi: 10.1080/17477891.2012.689252

Dyball, R., Brown, V. A., and Keen, M. (2009). "Towards sustainability: five strands of social learning," in *Social Learning Towards a Sustainable World. Principles, Perspectives, and Praxis*, ed. A. E. J. WALS (Dordrecht: Wageningen Academic Publishers), 181–194.

Fernandez, G., and Shaw, R. (2013). Youth council participation in disaster risk reduction in the philippines. *Int. J. Disast. Risk Sci.* 4, 126–136. doi: 10.1007/s13753-013-0014-x

Gaillard, J. C., and Mercer, J. (2012). From knowledge to action: bridging gaps in disaster risk reduction. *Prog. Hum. Geogr.* 37, 93–114. doi: 10.1177/0309132512446717

Garcia, C., and Fearnley, C. J. (2012). Evaluating critical links in early warning systems for natural hazards. *Environ. Hazards* 11, 123–137. doi: 10.1080/17477891.2011.609877

Gibson, T., and Wisner, B. (2016). "Let's talk about you": opening space for local experience, action and learning in disaster risk reduction. *Disast. Prev. Manag.* 25, 664–684. doi: 10.1108/DPM-06-2016-0119

Giddens, A. (1990). *The Consequences of Modernity*. London: Polity Press.

Giordano, R., Liersch, S., Vurro, M., and Hirsch, D. (2010). Integrating local and technical knowledge to support soil salinity monitoring in the Amudarya river basin. *J. Environ. Manag.* 91, 1718–1729. doi: 10.1016/j.jenvman.2010.03.010

Giordano, R., Preziosi, E., and Romano, E. (2013). Integration of local and scientific knowledge to support drought impact monitoring: some hints from an Italian case study. *Nat. Hazards* 69, 523–544. doi: 10.1007/s11069-013-0724-9

Glantz, M. H., and Ramírez, I. J. (2018). Improvisation in the time of disaster. *Environment* 60, 4–17. doi: 10.1080/00139157.2018.1495496

Global Network of Civil Society Organizations for Disaster Reduction (2013). *Views From the Frontline: Beyond 2015*. Available at: https://www.gndr.org/programmes/vfl/itemlist/category/168.html

Guadagno, L. (2016). Human mobility in the Sendai framework for disaster risk reduction. *Int. J. Disast. Risk Sci.* 7, 30–40. doi: 10.1007/s13753-016-0077-6

Heiss, R., and Matthes, J. (2017). Citizen science in the social sciences: a call for more evidence. *GAIA* 26, 22–26. doi: 10.14512/gaia.26.1.7

Hilhorst, D., Baart, J., van der Haar, G., and Leeftink, F. M. (2015). Is disaster "normal" for indigenous people? Indigenous knowledge and coping practices. *Disast. Prev. Manag.* 24, 506–522. doi: 10.1108/DPM-02-2015-0027

Horita, F. E. A., Albuquerque, J. P., and Marchezini, V. (2018). Understanding the decision-making process in disaster risk monitoring and early-warning: a case study within a control room in Brazil. *Int. J. Disaster Risk Reduct.* 28, 22–31. doi: 10.1016/j.ijdrr.2018.01.034

Horita, F. E. A., Albuquerque, J. P., Marchezini, V., and Mendiondo, E. M. (2017). Bridging the gap between decision-making and emerging big data sources: an application of a model-based framework to disaster management in Brazil. *Decis. Support Syst.* 97, 12–22. doi: 10.1016/j.dss.2017.03.001

Internal Displacement Monitoring Centre [IDMC] (2015). *Global Estimates 2015: People Displaced by Disasters*. Geneva: Internal Displacement Monitoring Centre.

International Federation of the Red Cross and Red Crescent Societies [IFRC] (2012). *Community Early Warning Systems: Guiding Principles*. Geneva: IFRC.

Jacobi, P. R., and Franco, M. I. G. C. (2011). "Sustentabilidade, participação, aprendizagem social [sustainability, participation and social learning]," in *Aprendizagem Social- Diálogos e Ferramentas Participativas: Aprender Juntos para Cuidar da Água [Social Learning: Participatory Dialogues and Tools: Learning Together to Take Care of Water]*, ed. P. R. Jacobi (Brazil: IEE/PROCAM), 11–19.

Kelman, I. (2006). Warning for the 26 december 2004 Tsunamis. *Disast. Prev. Manag.* 15, 178–189. doi: 10.1108/09653560610654329

Kelman, I., and Glantz, M. H. (2014). "Early warning systems defined," in *Reducing Disaster: Early Warning Systems for Climate Change*, eds Z. Zommers and A. Singh (Dordrecht: Springer), 89–108. doi: 10.1007/978-94-017-8598-3_5

Kitchenham, B., and Charters, S. (2007). *Guidelines for Performing Systematic Literature Reviews in Software Engineering*. Goyang: Technical report EBSE.

Kou, G., and Wu, W. (2014). Multi-criteria decision analysis for emergency medical service assessment. *Ann. Oper. Res.* 223, 239–254. doi: 10.1007/s10479-014-1630-6

Kusumasari, B., and Alam, Q. (2012). Bridging the gaps: the role of local government capability and the management of a natural disaster in Bantul. Indonesia. *Nat. Hazards* 60, 761–779. doi: 10.1007/s11069-011-0016-1

Loureiro, C. F., and Layrargues, P. P. (2013). Ecologia política, justiça e educação ambiental crítica: perspectivas de aliança contra-hegemônica [Political ecology, justice, and critical environmental education: perspectives of a counter-hegemonic aliance]. *Trab. Educ. Saúde* 11, 53–71. doi: 10.1590/S1981-77462013000100004

Lumbroso, D., Brown, E., and Ranger, N. (2016). Stakeholders' perceptions of the overall effectiveness of early warning systems and risk assessments for weather-related hazards in Africa, the Caribbean and South Asia. *Nat. Hazards* 84, 2121–2144. doi: 10.1007/s11069-016-2537-0

Luo, Y., Shaw, R., Lin, H., and Joerin, J. (2014). Assessing response behaviour of debris-flows affected communities in Kaohsiung. Taiwan. *Nat. Hazards* 74, 1429–1448. doi: 10.1007/s11069-014-1258-5

Macherera, M., and Chimbari, M. J. (2016a). A review of studies on community based early warning systems. *Jàmbá* 8:206. doi: 10.4102/jamba.v8i1.206

Macherera, M., and Chimbari, M. J. (2016b). Developing a community-centred malaria early warning system based on indigenous knowledge: Gwanda district, Zimbabwe. *Jamba* 8:289. doi: 10.4102/jamba.v8i1.289

Marchezini, V., Trajber, R., Olivato, D., Muñoz, V. A., de Oliveira Pereira, F., and Oliveira Luz, A. E. (2017). Participatory early warning systems: youth, citizen science, and intergenerational dialogues on disaster risk reduction in Brazil. *Int. J. Disast. Risk Sci.* 8, 390–401. doi: 10.1007/s13753-017-0150-9

Maskrey, A. (2011). Revisiting community-based disaster risk management revisiting community-based disaster risk management. *Environ. Hazards* 10, 42–52. doi: 10.3763/ehaz.2011.0005

Mercer, J., Kelman, I., Taranis, L., and Suchet-Pearson, S. (2010). Framework for integrating indigenous and scientific knowledge for disaster risk reduction. *Disasters* 34, 214–239. doi: 10.1111/j.1467-7717.2009.01126.x

Michoud, C., Bazin, S., Blikra, L. H., Derron, M. H., and Jaboyedoff, M. (2013). Experiences from site-specific landslide early warning systems. *Nat. Hazards Earth Syst. Sci.* 13, 2659–2673. doi: 10.5194/nhess-13-2659-2013

Mulyasari, F., and Shaw, R. (2013). Role of women as risk communicators to enhance disaster resilience of Bandung, Indonesia. *Nat. Hazards* 69, 2137–2160. doi: 10.1007/s11069-013-0798-4

Mustafa, D., Gioli, G., Qazi, S., Waraich, R., Rehman, A., and Zahoor, R. (2015). Gendering flood early warning systems: the case of Pakistan. *Environ. Hazards* 14, 312–328. doi: 10.1080/17477891.2015.1075859

Muzenda-Mudavanhu, C., Manyena, B., and Collins, A. E. (2016). Disaster risk reduction knowledge among children in Muzarabani district, Zimbabwe. *Nat. Hazards* 84, 911–931. doi: 10.1007/s11069-016-2465-z

Nguyen, H., Prabhakar, S. V. R. K., and Shaw, R. (2009). Adaptive drought risk reduction in cambodia: reality, perceptions and strategies. *Environ. Hazards* 8, 245–262. doi: 10.3763/ehaz.2009.0005

Olivato, D. (2013). *Análise da Participação Social no Context de Gestão de Riscos Ambientais na Bacia Hidrográfica do rio Indaiá, Ubatuba-SP-Brasil [Analysis of Social Participation in the Context of Risk Management in the Basin of the Indaiá River - Ubatuba – SP – Brazil]*. Ph.D. thesis, University of São Paulo, São Paulo.

Oliver-Smith, A., Alcántara-Ayala, I., Burton, I., and Lavell, A. (2016). *Forensic Investigations of Disasters (FORIN): A Conceptual Framework and Guide to Research*. Beijing: Integrated Research on Disaster Risk. doi: 10.14350/sc.02

Panda, A. (2016). Exploring climate change perceptions, rainfall trends and perceived barriers to adaptation in a drought affected region in India. *Nat. Hazards* 84, 777–796. doi: 10.1007/s11069-016-2456-0

Paveglio, T. B., Carroll, M. S., and Jakes, P. J. (2010). Alternatives to evacuation during wildland fire: exploring adaptive capacity in one Idaho community. *Environ. Hazards* 9, 379–394. doi: 10.3763/ehaz.2010.0060

Petersen, K., Feldt, R., Mujtaba, S., and Mattsson, M. (2008). Systematic mapping studies in software engineering. *EASE* 8, 68–77.

Preuner, P., Scolobig, A., Linnerooth Bayer, J., Ottowitz, D., Hoyer, S., and Jochum, B. (2017). A participatory process to develop a landslide warning system: paradoxes of responsibility sharing in a case study in upper Austria. *Resources* 6:54. doi: 10.3390/resources6040054

Quansah, J. E., Engel, B., and Rochon, G. L. (2010). Early warning systems: a review. *J. Terr. Obs.* 2, 24–44.

Šakić Trogrlić, R., Wright, G. B., Adeloye, A. J., Duncan, M. J., and Mwale, F. (2017). Taking stock of community-based flood risk management in Malawi: different stakeholders, different perspectives. *Environ. Hazards* 17, 107-127. doi: 10.1080/17477891.2017.1381582

Santos, R. F. (2004). *Planejamento Ambiental: Teoria e Prática [Environmental Planning: Theory and Practice]*. Brazil: Editora Oficina dos textos.

Stokoe, R. M. (2016). Putting people at the centre of tornado warnings: how perception analysis can cut fatalities. *Int. J. Disast. Risk Reduct.* 17, 137–153. doi: 10.1016/j.ijdrr.2016.04.004

Stone, J., Barclay, J., Simmons, P., Cole, P. D., Loughlin, S. C., Ramón, P., et al. (2014). Risk reduction through community-based monitoring: the vigías of Tungurahua, Ecuador. *J. Appl. Volc.* 3:11. doi: 10.1186/s13617-014-0011-9

Tenório, F. G., and Rozenberg, J. E. (1997). Gestão pública e cidadania: metodologias participativas em ação [public management and citizenship: participatory methodologies in practice]. *Revista da Administração Pública* 1, 1–37.

Teschenhausen, A. R. R. V. (2015). *In the Crowd we Trust: Role and Challenges of Crowdsourcing and Citizen Science in the Context of the Data Revolution – A Transdisciplinary Approach*. Ph.D. thesis, Universities of Leipzig, Vienna

Thomalla, F., and Larsen, R. K. (2010). Resilience in the context of tsunami early warning systems and community disaster preparedness in the Indian Ocean Region. *Environ. Hazards* 9, 249–265. doi: 10.3763/ehaz.2010.0051

Tyler, M., and Fairbrother, P. (2018). Gender, households, and decision-making for wildfire safety. *Disasters* 42, 697–718. doi: 10.1111/disa.12285

United Nations International Strategy for Disaster Reduction [UNISDR] (2005). *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters*. Geneva: UNISDR.

United Nations International Strategy for Disaster Reduction [UNISDR] (2006a). *Developing Early Warning Systems: A Checklist*. Bonn: UNISDR.

United Nations International Strategy for Disaster Reduction [UNISDR] (2006b). *Global Survey of Early Warning Systems: An Assessment of Capacities, Gaps and Opportunities Towards Building a Comprehensive Global Early Warning System for all Natural Hazards*. Geneva: UNISDR.

United Nations International Strategy for Disaster Reduction [UNISDR] (2009). *Terminology: Basic Terms of Disaster Risk Reduction*. Available at: https://www.unisdr.org/we/inform/publications/7817 [accessed March 1, 2018].

United Nations International Strategy for Disaster Reduction [UNISDR] (2015). *Sendai Framework for Disaster Risk Reduction 2015 – 2030*. Available at: http://www.wcdrr.org/uploads/Sendai_Framework_for_Disaster_Risk_Reduction_2015-2030.pdf [Accessed Aug 2018].

United Nations International Strategy for Disaster Reduction [UNISDR] (2016). *Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction*. Available at: https://www.preventionweb.net/files/50683_oiewgreportenglish.pdf [accessed May 1, 2018].

Villagrán de León, J. C. (2012). "Early warning principles and practices," in *Handbook of Hazards and Disaster Risk Reduction and Management*, eds B. Wisner, J. C. Gaillard, and I. Kelman (Abingdon: Routledge), 481–492.

Villagrán de León, J. C., Bogardi, J., Dannenmann, S., and Basher, R. (2006). Early warning systems in the context of disaster risk management Entwickl. *Ländlicher Raum.* 2, 23–25.

Zia, A., and Wagner, C. H. (2015). Mainstreaming early warning systems in development and planning processes: multilevel implementation of sendai framework in Indus and Sahel. *Int. J. Disast. Risk Sci.* 6, 189–199. doi: 10.1007/s13753-015-0048-3

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.