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Global Mapping of Citizen Science Projects for Disaster Risk Reduction

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Citizen science for disaster risk reduction (DRR) holds huge promise and has demonstrated success in advancing scientific knowledge, providing early warning of hazards, and contributed to the assessment and management of impacts. While many existing studies focus on the performance of specific citizen science examples, this paper goes beyond this approach to present a systematic global mapping of citizen science used for DRR in order to draw out broader insights across diverse methods, initiatives, hazards and country contexts. The systematic mapping analyzed a total of 106 cases of citizen science applied to DRR across all continents. Unlike many existing reviews of citizen science initiatives, relevance to the disaster risk context led us to 'open up' our mapping to a broader definition of what might constitute citizen science, including participatory research and narrative-based approaches. By taking a wider view of citizen science and opening up to other disciplinary practices as valid ways of knowing risks and hazards, we also capture these alternative examples and discuss their relevance for aiding effective decision-making around risk reduction. Based on this analysis we draw out lessons for future research and practice of citizen science for DRR including the need to: build interconnections between disparate citizen science methods and practitioners; address multi-dimensionality within and across hazard cycles; and develop principles and frameworks for evaluating citizen science initiatives that not only ensure scientific competence but also attend to questions of equity, responsibility and the empowerment of those most vulnerable to disaster risk.

Keywords: citizen science (CS), participation, narrative, disaster risk reduction, knowledge

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INTRODUCTION

Citizen science, or the participation of people from outside professional organizations in the gathering or analysis of scientific data, is now a well-established field of research and an important trend in scientific practice (Bonney et al., 2009b; Haklay, 2013). From its origin, citizen science has included participatory practices in shaping and guiding scientific and social scientific research to local needs (Irwin, 1995), as well as the provision of 'amateur' observational data to facilitate scientific understanding and create improved public understanding of science (Bonney, 1996). A large evidence base exists of the positive contribution of people from all walks of life to diverse scientific fields from, for example, improving understanding of avian biological patterns (e.g., Sullivan et al., 2009) to galaxy classification (e.g., Fortson et al., 2013). Consequently, Strasser et al. (2018) contend that current practices and expectations of citizen science most closely resemble those which follow the norms and values of institutional scientific approaches. However, while citizen science applied in this way is a useful tool for collection and analysis of large datasets, it also has a potentially valuable role in the rapid generation and sharing of information. This needs to draw not only on its origins and subsequent development as a tool for opening up discourse, and scientific data-gathering, but also to include experiential knowledge and knowledge situated in the socio-cultural context in which it is gathered (Irwin, 1995). Perhaps none more so than in hazard-prone settings where people can provide authorities with 'ground truth' of the occurrence and impact of hazardous natural events such as landslides, floods and severe weather. Not only can this information act as an early warning, which may help to save lives and livelihoods, it also has the potential to generate shared understandings of hazardous phenomena, improve communication and help communities at risk take actions to build their resilience during, after, and in preparation for future hazardous events.

To understand where practice and advances in citizen science might be most effective in this context it is necessary to consider the context of the disaster risk reduction (DRR) agenda. DRR broadly aims to anticipate and reduce the damage caused by natural hazards (for definitions please refer to a glossary in the **Appendix**). This is typically achieved through disaster risk management (DRM) which is the implementation of measures that create an ethic of prevention, and can involve systematic efforts to analyze and reduce the causal factors of disaster risk. More recently, these risks are understood to be social and culturally constructed in hazard-prone areas (e.g., Desai and Lavell, 2015). Disasters disproportionately impact those in developing world settings, and often the most vulnerable sectors of society in those settings (UNISDR, 2015) and currently there is growing recognition that successful DRM should be integrated within sustainable development by offering a contribution to social well-being and positive development of individuals and communities. This is most clearly conceptualized through three avenues: the prospective avoidance of further risk creation, the corrective mitigation of existing risk, and strengthening measures that can support the absorptive capacities of individuals and societies against the shocks generated by hazardous events. There is therefore strong potential for the contribution of citizen science in resource-constrained settings to support these goals, but particularly where it draws on citizen science traditions that encourage the integration of scientific-technological knowledge with experiential and contextual knowledge. In particular it should be aligned with the seven global targets[1] of the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015) and should clearly consider how it intersects or complement participatory methodologies associated with inclusive action on disaster risk. However, this alignment and the emphasis on the social and cultural construction of risks as well as the occurrence of the associated hazards suggests approaches in citizen science that engage with these multiple dimensions to risk may be more effective.

Hazard-centered, technology-led citizen science for DRR (e.g., utilizing sensors to collect data about hazards) are the most conventional initiatives and have been very effective in many disaster contexts. Yet, the use of Information and Communication Technologies (ICT) does not always guarantee high data quality and participant engagement (Wiggins, 2013). There has been appeal for citizen science scholars and practitioners to embrace tools used in other disciplines, such as social sciences (Hecker et al., 2018).

Although not currently aligned with or related to citizen science, DRR scholars and practitioners (e.g., Wisner et al., 2004; Kelman et al., 2011; Maskrey, 2011; Mercer et al., 2012; Scolobig et al., 2015a), as a consequence of the emphasis on the social construction of risk, advocate approaches that put those at risk at the center of risk reducing initiatives. These approaches are sometimes referred to as 'people-centered' DRR and are often focused at the community scale and emphasize the empowerment of individuals within a community to 'own their risk' in the longer term and, where appropriate, act to reduce it. In comparison to projects that overtly label themselves as citizen science, participatory approaches to DRR typically focus more squarely on empowering people to foster longer-term preparedness development of their own mitigation strategies, and influence on decision-making processes at multiple scales. Nonetheless there is clearly strong potential for intersection and learning between these two knowledge traditions. There are examples of 'people-centered' DRR where communities threatened by hazards have successfully mapped their risk environment to articulate and generate knowledge of long-term impacts (Cronin et al., 2004a; Cadag et al., 2018), or where communities have influenced decision-making processes (e.g., Stone et al., 2014). There are, however, fewer that deal with immediate hazard threat or that work across multiple scales. The argument for considering these different epistemologies in parallel is clear: it is already recognized that the integration of 'local' people-centered DRR with risk management plans and processes at other scales could lead to a 'sustainable reduction in disaster risks over time' (Maskrey, 2011). This would be further reinforced

[1]The seven global targets are to: (a) Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005-2015; (b) Substantially reduce the number of affected people globally by 2030, aiming to lower average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015; (c) Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030; (d) Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030; (e) Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020; (f) Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this Framework by 2030; (g) Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030. UNISDR 2015. Sendai Framework for Disaster Risk Reduction 2015–2030.

by deepening collaboration between citizens at risk and those responsible for scientific information gathering or emergency response. This could benefit both participants and scientists, which should generate sustained involvement in community-based risk reduction projects. Further, by considering the intersection of more traditional citizen science projects with participatory processes associated with DRR there is also the potential to more explicitly work to equalize access to scientific data and knowledge regardless of wealth, status or gender, consistent with the Global Goals for Sustainable Development (UNISDR, 2015).

If there is potential benefit from looking beyond hazard-focused citizen science and integrating tools from participatory research for DRR, there may also be advantage in cross-fertilization of techniques more commonly used in the arts and humanities. Such interdisciplinary approaches are often applied in DRR research, and examples also exist from citizen science (frequently under the header of ‘Digital Humanities’). We know that scientific, socio-scientific, cultural and political knowledge can all contribute to the reduction of disaster risk but are often considered in isolation, or underutilized in practice. We have also established that successful DRM demands improved experiential and situational knowledge and means to empower the citizens at risk, both of which can be offered by drawing on methods and techniques from the humanities. Attempts to understand the crucial ingredients for success in citizen science should also draw on these knowledge traditions.

In this paper, which attempts to understand how citizen science is and could be applied to DRR, we extend our characterization and analysis of citizen science from purely science and technology-led initiatives to include projects which adopt participatory methods and explore the role of vernacular and narratives for DRR. As more interdisciplinary fields are emerging applied to the prevention of disastrous outcomes from natural hazards, we consider it timely to map out the range of activities across a broader suite of citizen science techniques and consider lessons and synergies across diverse fields. This is already in line with some interpretations of citizen science (Irwin, 1995; People’s Knowledge Editorial Collective, 2016). We argue that the field of practice (or epistemology) from which the technique draws is of secondary importance to identifying how and when positive outcomes occur for communities at risk. We review citizen science initiatives for DRR by mapping >10 years trends across disciplines, hazard and location in an attempt to understand the components of citizen science projects that determine success, and as a corollary, what citizen science initiatives have to offer DRR.

We begin by providing some context to our suite of citizen science techniques followed by a description of the approach to our global mapping, and the interdisciplinary workshop that informed it. We then present our global mapping results and analysis followed by a discussion of the challenges that DRR poses to citizen science and the benefits of taking a broader approach by ‘opening up’ citizen science initiatives to diverse disciplines.

CITIZEN SCIENCE SUITE OF TECHNIQUES: CONTEXT

Traditional Scientific Technological Approaches to Citizen Science

Technological developments have facilitated a rapid rise in citizen science initiatives, often labeled as crowdsourcing – a voluntary activity by a large, unsolicited group of people (the crowd) who contribute information, ideas or services, usually via the internet. In citizen science initiatives applied to DRR, this type of information is sometimes referred to as Volunteered Geographic Information. The ‘crowd’ can use their digital devices to capture photos and record real-time observations of hazardous events or damage, and/or analyze images *post hoc*. This information can support emergency responders at the time, as well as relieve pressure on disaster analysts post-event. Smartphone accelerometers and Global Positioning Systems can detect earthquakes and potentially provide warnings (Ervasti et al., 2011; Minson et al., 2015; Kong et al., 2016), for example, the proof-of-concept MyShake smartphone seismic network harnesses smartphone sensors to detect magnitude five earthquakes and above at distances of 10 km or less. This information could be used to support early warning systems in regions with traditional seismic and geodetic networks by helping to confirm earthquake detection, and in regions without traditional seismic networks (which often have high smartphone ownership), and could be used to deliver alerts (Kong et al., 2016). Games, apps and online activities such as mapping (e.g., via OpenStreetMap) are becoming more popular with the public and researchers to be able to record observations, monitor hazards and provide early warning (Palen et al., 2007, 2015; Mani et al., 2016; Mossoux et al., 2016). Web-enabled databases are used for the public to submit observations directly about hazards, such as volcanic ash distribution (Wallace et al., 2015) and about hazard impacts on, for example, infrastructure (Baum et al., 2014). This information is useful for monitoring agencies to assess the characteristics of, for example, a volcanic eruption plume, which can be used to update ashfall advisories for aviation. Social media data can be leveraged and transformed into useful and useable information for both the public at risk, emergency responders and decision makers. This was the central hypothesis of the PetaJakarta.org project which collected verified reports of flooding from residents of Jakarta via Twitter. The geo-located tweets provided a valuable real-time ‘knowledge network’ of flood events of unparalleled spatial and temporal resolution (Holderness and Turpin, 2015).

Participatory Approaches in DRR and Their Intersection With Citizen Science

While traditional citizen science approaches are likely to stem from science and technology, by definition the involvement of the wider public makes citizen science initiatives a participatory activity. Indeed, one of the terms that can be used for this field is Public Participation in Scientific Research (Bonney et al., 2009a). Within the context of DRR, participatory activities are typically classified via their framing or originator from ‘bottom up' or 'grassroots,' i.e., conceived, planned and driven by citizens, through to 'top down', i.e., organized campaigns usually driven by non-governmental organizations, local political actors or researchers, framings familiar to citizen science. Depending on the research goal, approaches across the spectrum can achieve success, but most participatory activities do not have new information about hazards or hazard impacts as their core goal and so would not usually be regarded as closely aligned with citizen science. In DRR, participation is usually a core principle or perceived as a key dimension of success. For example, the guiding principles of the Sendai Framework for Disaster Risk Reduction requires "all-of-society engagement and partnership," for participation to be empowering, inclusive, accessible and non-discriminatory, and that "special attention should be paid to the improvement of organized voluntary work of citizens" (UNISDR, 2015, p. 13). There are, however, increasing numbers of 'participatory DRR' projects that take a more mid-ground, co-creative approach where both scientists and citizens use and generate different forms of knowledge to integrate new understandings and create a shared agenda. Numerous examples of participatory initiatives exist that align with these guiding principles and the wider aims of citizen science, from the development and evolution of a community-based volcano monitoring network at Tungurahua volcano in Ecuador (Stone et al., 2014; Armijos et al., 2017), to the initiation of 'slope watchwomen' to inspect the landslide-prone slopes in the city of Manizales, Colombia (Mejía Prieto et al., 2006; Hermelin and Bedoya, 2008).

Use of Narratives in Citizen Science for Disaster Risk Reduction

Developing the idea that citizen science in the context of DRR is the generation of any relevant new knowledge, there is mounting evidence that narrative (social and/or historical) has a role to play in preparedness and recovery. For example, on Simeulue Island in Indonesia, thousands of lives were saved from the impacts of the 26 December 2004 tsunami by people shouting *Smong* (meaning 'tsunami in'). This is a story told in lullabies, poems and songs, inherited and shared over generations. On hearing the word following an earthquake, people move to higher ground (Syafwina, 2014). The 'Strengthening Resilience in Volcanic Areas' (STREVA) project created oral history films to capture community experience of volcanic eruptions in Colombia and St. Vincent and the Grenadines, which proved not only to be a cathartic act for survivors sharing their experiences on film, but also motivated audiences to consider ownership of risk and potential actions to reduce it (Hicks et al., 2017). Similarly in New Zealand, the production of a dance performance assisted the recovery of those that had been affected by the Christchurch earthquake (Egan and Quigley, 2015).

Beyond these examples, narrative could have a number of functions in relation to citizen science more broadly, and not only for DRR: (1) as a data source from which information can be extracted (Stone et al., 2014); (2) as a data object, e.g., for bonding and social connection (social capital) (Chamlee-Wright, 2017); (3) as a tool for communication e.g., storytelling (Hicks et al., 2017); (4) as a resource to challenge dominant narratives; and (5) as a tool to evaluate a project or intervention (Constant and Roberts, 2017).

RESEARCH METHODOLOGY

Context and Framing

This paper stems from a 14-month[2] research project called "Harnessing 'citizen science' to reinforce resilience to environmental disasters: creating an evidence base and community of practice." The aim of our project was to understand how citizen science is currently applied to DRR objectives in the face of natural hazards, and how it might be more effectively applied in the future. We also aimed to create an outward facing network of researchers interested in evidence-based approaches to applying a broad suite of citizen science techniques to environmental hazards. In this context, and drawing on the different knowledge traditions outlined above, our definition of citizen science is as follows: "*Citizen science places citizens at the center of a process that generates new knowledge for disaster risk reduction*[3]." In a recent review of citizen science terminology, Eitzel et al. (2017) concluded that no single term is appropriate for all contexts and in trying to develop a new epistemic framework for citizen science (Strasser et al., 2018) argue that opening up definitions of knowledge and participation in citizen science could 'result in a different kind of science and a different kind of knowledge' that has the potential to transform understandings of the natural world. In parallel, we conclude that the application of citizen science to DRR needs to be appropriate to that context, so we deliberately gathered evidence widely across disciplines and epistemologies. Our definition uses the word 'knowledge' instead of 'science' to acknowledge this widening from scientific norms to define the landscape of DRR-focused citizen science projects across the world.

Initial Project Workshop

In April 2017, our first project workshop was held with 27 researchers[4] and international project partners[5] working across the physical and social sciences, arts and humanities, many of whom had been or were actively involved in citizen science projects, or came from knowledge traditions of relevance to citizen science in DRR contexts or the improvement of DRR outcomes. The aims of the workshop pertinent to this paper were: (a) discuss the synthesis of citizen science literature to date, particularly asking, *"are there conceptual crossovers between the*

[2] Project duration: January 2017 – March 2018.

[3] The United Nations Office for Disaster Risk Reduction (UNISDR) defines disaster risk as the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time as a function of hazard, exposure, vulnerability and capacity. So, disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk.

[4] Researchers (United Kingdom-based) were from University of East Anglia (representation from five schools), British Geological Survey, University of Bristol, University of Durham (representation from two schools), University College London (representation from two departments), University of Oxford, University of Essex, Kings College London and the University of Leeds.

[5] International partners were from Trinidad and Tobago, Nepal and Ecuador.

wider [as we are defining it] suite of citizen science projects?"; and (b) discuss the questions, *"what lessons can we learn from existing initiatives?"* and *"how can the design of future initiatives be improved?"* Key findings from region-specific analyses were introduced and we used breakout groups and plenary discussion to think about the development of our mapping framework and what makes an 'effective' citizen science project. After producing an initial list, we used a 'fantasy' citizen science project exercise based in St. Vincent and the Grenadines, to test and converge on key principles for successful citizen science that conforms to the wider goals of DRR (see section Discussion).

Global Citizen Science for DRR Project Mapping

Following the workshop, a literature mapping scoping note was sent to the project team for suggestions of potential cases to be included in our expanded review corpus. We requested that each case must involve some kind of citizen engagement with natural hazards (e.g., recording observations or participatory mapping), but could be from any disciplinary area. However, our deliberately broad definition of citizen science, differing epistemologies within the multi-disciplinary team and the breadth and number of studies made it challenging to bound our literature mapping. As a result we drew on a systematic mapping method which has been developed to map across diverse forms and systems of public participation in science and environmental issues (Chilvers et al., 2018). This method involves the following steps: (i) *scoping* the literature, framework for analysis and search terms; (ii) *expert panel feedback,* in this case from workshop participants; (iii) *searching and screening* through systematic searches of academic literatures based on key terms and synonyms relating to the 'how' (i.e., method), 'who' (i.e., who participates) and the object (e.g., hazard or problem) of citizen science initiatives; and (iv) *document and case study analysis* of cases screened into the literature corpus to identify key patterns and trends in citizen science for DRR.

Drawing on this approach we developed a list of search terms which were synonyms of 'how,' i.e., the model of citizen science or the means through which citizens engage (the process), to be searched alongside synonyms of 'who,' i.e., who are the participants, synonyms of 'what,' i.e., what is the object of citizen science or what problem is it addressing, and synonyms of outcomes or products of citizen science. Originally a project-wide collaborative exercise, it resulted in a long list of synonyms that generated 1.26 million results from peer reviewed sources alone. Acknowledging that it would be beyond the scope of the project to review this many sources, the authors' final selected search terms were: "citizen science," crowdsource*, particip*, narrative, story*, disaster and hazard. Restricting the search terms was necessary to make the global scope of the mapping workable, although it will have restricted attention to particular meanings of citizen science to some degree and led to the exclusion of some studies from our searches. However, this allowed us to sample representative projects that might demonstrate effective approaches in achieving broad goals aligned with current challenges in DRR and management. It is also important to note that we restricted the search to the academic peer-reviewed literature. Firstly, in this literature, there was more likely to be descriptions of framing rationalization, measures of success and analysis of the outcomes from the project. Secondly, although there are many more cases within the gray literature, for example in World Bank reports (GFDRR, 2018), the scale of this initial mapping made their inclusion difficult. While this means that some cases will therefore have been excluded, it does signify the need to explore diverse forms of citizen science and obtain evidence for citizen science projects that push beyond codified documentation of practice. We completed our searches through the academic search engines Web of Knowledge and Scopus[6] and filtered by subject in order to reduce the number of irrelevant cases. There was no restriction imposed on date of publication as our preliminary searches established that most citizen science projects related to hazards were conducted, or at least published, in the last 10 years. Duplicates generated from the two search engines were filtered, conference proceedings were omitted and then the results were manually screened to identify relevant cases. A total of 305 studies were identified at the first screening stage.

We then categorized the corpus of cases in order to map the diversities and patterns of projects across a set of variables (**Table 1**). The initial set of variables for our first iteration of coding were: (1) project country focus (division into developing or developed countries); (2) whether it was a 'new' citizen science project, as compared to a review of a project or set of projects, and (3) whether it was in fact a citizen science project for DRR, as per our agreed definition. Coding against variables 2 and 3 condensed the number of relevant publications considerably, making a final corpus of 106 in total. Once the relevant publications had been screened we conducted a second round of coding to explore the projects in more depth. These variables broadly addressed the who, what, why, where, when and how and were chosen to help us identify geographical and hazard focus (and potentially patterns) of projects, the broad methodological approach and the proportion of projects initiated at particular times along the disaster continuum (i.e., before, during and after). Along with other data such as project aims, specific methodologies, project participants and funding bodies (gathered in case interesting patterns emerged), we collected this information to help us understand the trends and landscape of citizen science projects and how they aligned with current challenges or best practice in DRM, and the ingredients for and barriers to success. It is important to understand this was not to critique any individual study (which may have only serendipitously included goals associated with DRM as a result of another chief aim) but to use them to collectively understand current practice and knowledge and project framing.

Where available, we also coded information about the nature of the association between scientist and participants (**Table 2**), i.e., were both scientists and citizens outside of the region/country where the hazard occurred? Were scientists outside and participants experiencing the hazard? Were both inside the country? Were they collective movements (grassroots)? Related to this, we documented the type of interaction between the two (collaborative, collaborative but with strong direction

[6]Web searches were conducted between the 25–27th February 2018.

TABLE 1 | Inclusion criteria and variables for global mapping of citizen science for DRR projects.

	Variable	Subdivision	Justification for testing
Coding #1	Project country focus	Developing or developed	To identify concentrations and absences of country focus.
	Primary research	New or review	Exclusion of reviews – had to be an original project
	Definition consistency	Yes or no	Exclusion of projects not satisfying our agreed definition
Coding #2	Broad methodological category	• Participatory activities in DRR	To analyze quantity of projects attributed to each category and enable comparisons with other variables. Projects can be classified under more than one category
		• Crowdsourcing/tech-led	
		• Narratives used to interpret physical behavior from past events	
		• Narratives used to interpret social behavior	
	Hazard type	• Air quality	To identify patterns in hazard focus and compare against other variables.
		• Cyclone	
		• Earthquake	
		• Fires (wild/bush)	
		• Flood	
		• Hurricane	
		• Lahar	
		• Landslide	
		• Rain	
		• Space Weather	
		• Storm	
		• Storm surge	
		• Tsunami	
		• Typhoon	
		• Volcanic eruption	
		• All hazards	
		• Multiple hazards	
		• Hazard not specified	
	Project location	*Multiple locations (see Results for details)*	To identify patterns in project location and compare against other variables. To help answer the question:
	Disaster continuum position	• Before (preparedness phase)	To identify patterns in project position in the disaster continuum. We also noted when projects crossed multiple phases.
		• During (response phase)	
		• After (recovery phase)	

from scientists, extractive, and analytical). These variables relate closely to the 'contributive,' 'collaborative' and 'co-created' models of cooperation in citizen science projects (Bonney et al., 2009b; Shirk et al., 2012) and acknowledge the power relationships between participants, an important dimension of participatory methodologies in DRR. They also allow us to reflect on the extent to which apparently different knowledge traditions have potential to intersect or learn from one another. The variables 'extractive' and 'analytical' refer to instances where participants are data subjects (with no direct benefits to them for participation) and where the participants explore and interpret information they, or others, have gathered, respectively. If documented, we recorded measures of success, acknowledged pitfalls of the project(s) and whether the project(s) met or expressed parallel principles to those that we had synthesized as a consequence of the first workshop (see section Discussion for details on the principles). The details of our corpus of cases are in a spreadsheet in the **Supplementary Materials**, and on the project website citizensciencedrr.com.

RESULTS AND ANALYSIS

This section details the characterization of our cases by country focus, by hazard focus, by stage along the disaster continuum and by model of cooperation between scientist and citizen. As stated above, we take our global mapping beyond existing reviews of the citizen science literature (e.g., Conrad and Hilchey, 2011) by opening up our mapping to include projects using methodologies more commonly associated with social sciences, arts and humanities (i.e., participatory research and narrative based approaches). These cases are also characterized.

TABLE 2 | Typology of relative locality between scientist and participant to the hazard **(A)** and a typology of the nature of association between scientist and participant in citizen science projects/initiatives for DRR **(B)**.

(A)

Relative locality between scientist and participant to the hazard	Definition
'In–In'	Both scientist and participant were located in the same region/country experiencing the hazard
'Out–In'	Scientists were outside the region/country and participants were inside
'Out–Out'	Both scientist and participant were outside of the region/country experiencing the hazard
Grassroots	Collective movements devised and driven completely by participants experiencing the hazard

(B)

Nature of scientist/participant association	Definition
Collaborative (also known as co-created with reference to Shirk et al., 2012)	Participants and scientists equally share and own the research question(s), project design, data gathering, analysis, and interpretation.
Collaborative but with strong direction from scientists (collaborative, with reference to Shirk et al., 2012)	Participants contribute to data collection, analysis and interpretation but do not direct research questions.
Extractive	Participants are data subjects with no direct benefit from participating.
Analytical	Participants explore and interpret information either they, or others, have gathered.

Characterization of Cases per Country

Of our corpus of cases (#106) there were relatively equal numbers of citizen science for DRR projects based in both developed and developing countries. **Figure 1** shows a global map of country focus for the projects we identified in our analysis. While there is a relatively high diversity of study areas in which citizen science for DRR projects were focused – with a notable exception of the African continent – there are no examples of follow-on or iterative projects in any one location. There is one example where the lead author used a participatory approach in one location, developed and applied it in another (Cronin et al., 2004a,b). Three out of four publications from Ecuador also have a single citizen science 'case' as the focus (Stone et al., 2014; Mothes et al., 2015; Armijos et al., 2017). It is also important to note that some projects did comparative studies involving two or more countries, which have all been included in the characterization.

For most developing countries, there were projects that addressed one or more of the top three hazards contributing to average annual reported losses (EM-DAT). For the United States, which had the highest number of projects, this was storms (including hurricanes), flood and wildfire. The suite of projects also included examples from each stage along the disaster continuum and each of our four 'method' categories (**Table 1**). The hazard focus of Australia-based projects were fires and flooding, despite storm surge being their second largest contributor. New Zealand-based projects were focused on flood, storms and volcanic eruptions, and projects were almost always initiated after a disaster. Of developing country examples, the Philippines had relatively high numbers of projects focusing on wind, storm surge, and earthquakes, as did the Caribbean, albeit with a dominance of projects based in Haiti. For Indonesia, projects focused on volcanic eruptions, floods, and earthquakes. While India has one of the highest occurrence of disasters in Asia - with flooding making up 76% of the hazard contribution to the average annual losses – there was only one project example from our mapping. Our mapping also only highlighted only two examples from Africa (note that the Aalst et al., 2008 study adopted the same approach in two African countries). This could be due to differences in the historical and social relationship with what constitutes 'science' and 'knowledge' (Leach and Fairhead, 2002), although arguably given our 'opened up' approach to the literature search, examples rooted in indigenous knowledge theory and practice, rather than citizen science, should have been captured.

Methodological Characterization of Cases

Against our four 'method' categories (**Table 1**), 52 projects used participatory approaches as the core methodology, 59 were related to crowdsourcing and/or science/technology-led, 14 projects used narratives to interpret physical behavior from past events, and 12 used narratives to interpret and understand social behavior and response to past events. Note that several projects were coded against more than one category. For example, the study by Armijos et al. (2017) was coded against all four categories. Seven of the 36 publications that reviewed citizen science projects for DRR were additionally a discrete study adopting one or more of these methodological categories, so were included in the dataset.

Characterization of Cases by Hazard

Hazard characterization of the projects reveals that flooding and earthquakes are the most frequent focus of citizen science for DRR projects, with more than double the number of earthquake and flood projects based in developed countries than developing. For earthquakes particularly, this is likely because of the prevalence of crowdsourcing-related projects for earthquake reporting (e.g., Wald et al., 2012; Kong et al., 2016;

FIGURE 1 | Global map showing numbers of published citizen science projects with a DRR focus. Argentina (Le Coz et al., 2016), Australia (Madsen and O'Mullan, 2013; Yates and Partridge, 2015; Haworth et al., 2016; Hung et al., 2016; Zhong et al., 2016; Haworth, 2018), Belgium (Mossoux et al., 2016), Brazil (Marchezini et al., 2017; Hirata et al., 2018), Canada (Tappenden, 2015; Díaz et al., 2016; Rieger, 2016), Montserrat (Loughlin et al., 2002), Chile (Usón et al., 2016), China (Peng, 2017; Qi et al., 2017; Svensson, 2017), Colombia (Hermelin and Bedoya, 2008; Loaiza et al., 2017), Cambodia (Aalst et al., 2008), Costa Rica (Aalst et al., 2008), Czech Republic (Raška and Brázdil, 2015; Panek et al., 2017), Denmark (Frigerio et al., 2017), Democratic Republic of the Congo (De Albuquerque et al., 2016), Ecuador (Ibadango et al., 2007; Stone et al., 2014; Mothes et al., 2015; Armijos et al., 2017), Europe (Bossu et al., 2012; Wehn et al., 2015a; Maltoni et al., 2017). Finland (Frigerio et al., 2017), Global (Tapia et al., 2014; Bossu et al., 2016; Kong et al., 2016; Ramchurn et al., 2016; Jones et al., 2017; Ludwig et al., 2017), Grenada (Canevari-Luzardo et al., 2017), Haiti (Ghosh et al., 2011; Corbane et al., 2012; Liu, 2014; Palen et al., 2015; Saganeiti et al., 2017), India (Murthy et al., 2014), Indonesia (Karnawati et al., 2011a,b; Chatfield et al., 2013; Syafwina, 2014; Holderness and Turpin, 2015; Carley et al., 2016), Iran (Omidvar et al., 2011), Italy (Ginige et al., 2014; Scolobig et al., 2015b; Wehn et al., 2015b; Saganeiti et al., 2017), Japan (Ikeda and Nagasaka, 2011; Yamori, 2012; Appleby, 2013), Kenya (Aalst et al., 2008), Netherlands (Aalst et al., 2008; Wehn et al., 2015b), New Zealand (King et al., 2007; Bateman and Danby, 2013; Mutch and Marlowe, 2013; Carlton, 2015; Cretney, 2016; Le Coz et al., 2016; Marek et al., 2017), Philippines (Delica, 2003; Maceda et al., 2009; Abon et al., 2012; Palen et al., 2015; Fernandez and Shaw, 2016; Mejri et al., 2017), Saint Lucia (Joseph et al., 2015), Saudi Arabia (Al-Saggaf and Simmons, 2015), Solomon Islands (Cronin et al., 2004b), Taiwan (Liang et al., 2017), United Kingdom (Pennington et al., 2015; Wehn et al., 2015b; Kornakova and March, 2017), United States [All states (Palen et al., 2007; Baum et al., 2014; Murthy et al., 2014; Wallace et al., 2015; McCormick, 2016; Kornakova and March, 2017; Kirkpatrick, 2018); California (O'Brien and Mileti, 1992; Goodchild and Glennon, 2010; Ervasti et al., 2011); Florida (Godschalk et al., 2003); Gulf Coast (Kar, 2016); Louisiana (Chamlee-Wright and Storr, 2011); Minnesota (Kweit and Kweit, 2004); New York (Dailey and Starbird, 2014; Smith et al., 2015); Texas (Lue et al., 2014; Richardson and Maninger, 2016); Washington (Godschalk et al., 2003)]; Vanuatu (Cronin et al., 2004a), and Zambia (Aalst et al., 2008).

Liang et al., 2017; Peng, 2017), which usually (though not always) rely on a broad user group with access to a smartphone and the internet. There are more projects on landslides and volcanic eruptions in developing countries, likely to be due to the disproportionately severe impact of these events in developing countries (Dowling and Santi, 2014) resulting from a number of contributing factors such as development patterns, access to health care and emergency services and lack of early warning.

Characterization of Cases by Stage of the Disaster Continuum

A third of projects take place in the aftermath of disaster, likely attributable to the focus of financial and societal support for disaster response (e.g., Aldrich, 2012). The Sendai Framework for Action advises proactive planning and investment in DRR (UNISDR, 2015), but this is often challenging due to a lack of political commitment to resource DRR efforts for prioritization of other development problems (Lassa et al., 2019). Our mapping shows that most citizen science projects initiated before an event are participatory and collaborative in nature and in general tend to be focused around community-centered activities such as hazard mapping, monitoring or mitigation. Those projects concurrent with disaster are almost all associated with more traditional technology-driven citizen science, mostly using crowdsourcing via online mapping to support humanitarian efforts. Citizen science projects conducted after an event are a mixture of traditional citizen science using 'sci-tech' and participatory activities. Interestingly almost all of the projects that applied methods from the arts and humanities (particularly narratives) to generate new knowledge and understanding occurred after the event.

Characterization of Cases by Model of Cooperation Between Scientist and Participant

In terms of the relationship between scientist and participant, approximately 50 projects (47% of total) were classified as 'in-in' (i.e., both scientist and participant were located in the same region/country experiencing the hazard). Approximately 18 (17%) were coded as 'out-in' (i.e., scientists were outside the region/country and participants were inside), one as 'out-out' (i.e., both were outside of the region/country), and six as grassroots (i.e., collective movements devised and driven completely by participants experiencing the hazard). For some projects, it was not possible to determine the model of cooperation between scientist and participant. The majority of 'in-in' projects were either extractive in nature (i.e., where participants are data subjects) or collaborative, but with strong direction from scientists. The majority of 'out-in' projects were also collaborative but with strong direction from scientists. Of the grassroots initiatives we identified, there were relatively equal numbers of projects that were collaborative (none with strong direction from scientists), analytical or extractive.

DISCUSSION

Our global mapping shows that citizen science for DRR initiatives are being conducted across the world to help address some of the global challenges associated with disasters. While short-term success and sustainability of projects is variable, nonetheless, the discrete nature of the methods and cases is limiting opportunities for methodological innovation, active and broader networking of participants, and flexibility to adapt initiatives as conditions change. A key outcome from our mapping is that we can do much more to move beyond discrete methods and cases of citizen science for DRR to build linkages, connections and relationships more broadly. This would more closely align projects with DRR and help to address some live challenges (e.g., Desai and Lavell, 2015) in using DRM s as a tool to afford positive development trajectories. This finding is concurrent with evidence from other citizen science reviews in related fields (e.g., Hecker et al., 2018; Marchezini et al., 2018). For the remainder of this paper, we reflect on three key issues raised from our global mapping exercise.

Citizen Science for DRR Needs to Be Multi-Dimensional

Examining DRR-focused citizen science projects in a more holistic manner along the disaster continuum shows the significance of the temporal aspect of the initiatives, and how this affects success. During a disaster (or the response phase) is, generally speaking, the only part of the cycle that is *relatively* temporally constrained. Our mapping shows that most initiatives concurrent with disaster are technology-led citizen science designed to support humanitarian efforts. Whether this is volunteer mapping of hazards and impacts by altruistic 'outsiders' motivated to help people, or crowdsourced 'ground-truthing' by affected citizens themselves, volunteering to add to a dataset and generate new knowledge is often a passing interest during the time of crisis. This is not necessarily a detriment to any one particular initiative, and there are few examples of opportunities to nurture long-term loyalty to an initiative once the disaster has passed (Turk, 2017). Our mapping shows that there is a need to consider the application of citizen science for DRR in a more multi-dimensional way, particularly the connections and interrelations of methods throughout the disaster continuum.

Our mapping also shows that most citizen science initiatives are compartmentalized around specific hazards (**Figure 2**). Taking a multi-hazards approach to observing the world around us to account for differing rates of hazard occurrence and documenting the cumulative or even cascading impacts of most relevance to the communities at risk may help to foster continued citizen engagement in observing and monitoring environmental change, whether that be driven by rational egoism and/or collectivism (Baruch et al., 2016; Tipaldo and Allamano, 2016). This would align more clearly with prospective approaches to DRM that could anticipate and reduce the creation of new risks, or identify means to adapt to ongoing hazards. Our analysis shows that current initiatives tend to be bi-modal. Those underway before disasters occur tend to be participatory and collaborative in nature, and focused around community-centered activities such as hazard mapping, monitoring or mitigation. Those initiated afterward are more extractive or technology-led citizen science. Projects that apply methods from the arts and humanities tend to be associated with the recovery phases, or with the generation of knowledge of the impacts of past events. In both preparatory and recovery phases, there is often – but not always – more time for participants and designers of citizen science projects (it is noted that these can be the same) to develop initiatives that have more subtle, yet important, ingredients for ongoing success, for example, a longer project lifespan to help foster sustainable preparedness, or the flexibility to evolve and adapt to changing environmental and/or socio-economic conditions, which may include scaling up initiatives.

In a DRR context, the value of spatial and temporally focused citizen science initiatives could be strengthened by being part of a multi-method approach (Pelling, 2007) addressing all phases along the disaster continuum. A blending of citizen science initiatives applying successful, evidence-based methods across disciplines that are contextually appropriate before, during and after a disaster may help to influence decision-making processes at multiple scales although this is a challenging task that requires appropriate resources.

Cross-Fertilization of Communities Will Bring Innovation

We identified that similar numbers of projects took either a technology-led approach or a participatory approach

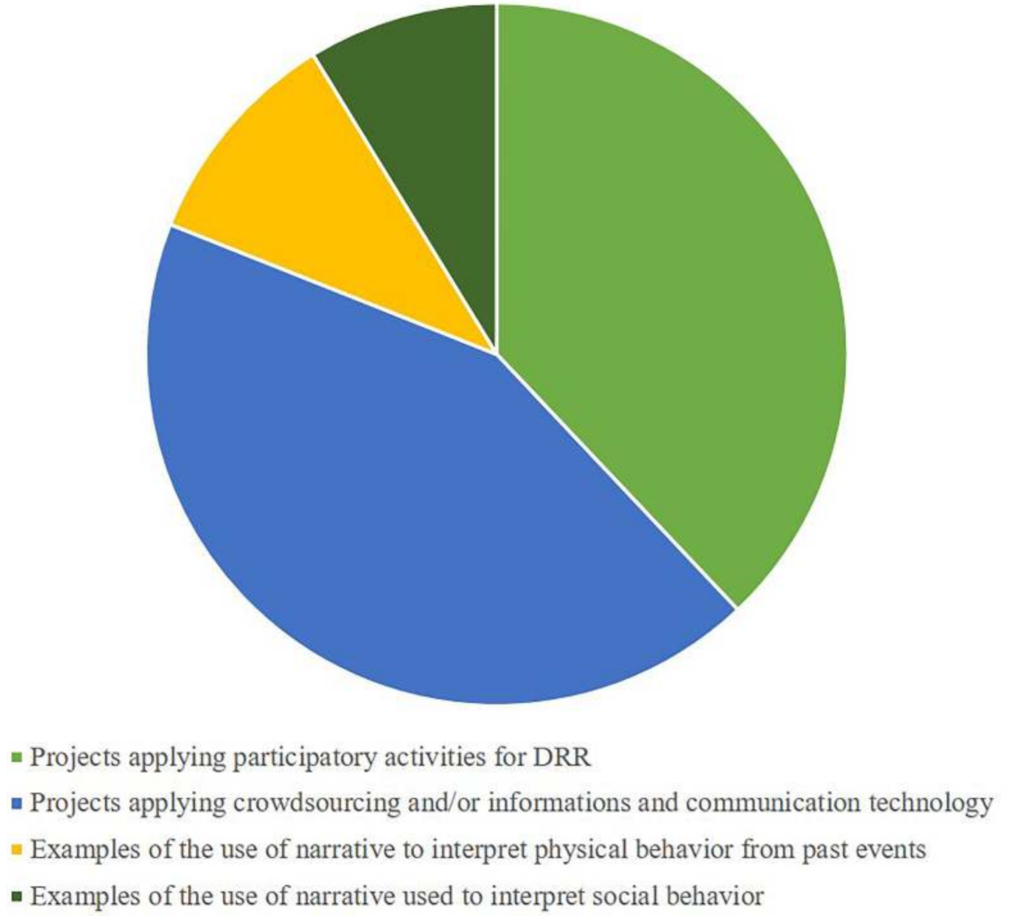

FIGURE 2 | Methodological characterization of cases.

to their initiatives (some projects took both). Where we could identify the relationships between the participants and the researchers there was a rough equivalency between projects that were largely extractive (where participants were data subjects or providing data with no direct benefits to them beyond altruism) or collaborative. Comparatively few projects explored the role of narrative in knowing hazard and risk, and the majority of those were extractive in nature. Relatively few projects had been initiated and mobilized by the communities themselves [referred to as 'grassroots' in our analysis (**Supplementary Materials**)]. This reflects the broader pattern of research in both citizen science research more generally, which has been dominantly science-centered (largely driven by scientists and of benefit to scientists), and DRR research which is dominantly people-centered (although this is not to say that DRR research is not scientific). Bridging these two parallel fields of research specifically for citizen science for DRR requires consideration about the crossover between them. Citizen science *requires* the participation of citizens in the scientific process, and while participatory approaches also requires the participation of citizens, it need not necessarily involve science or scientists. This is why, for this study, we use the word 'knowledge' in place of 'science.' If we consider citizen science as knowledge making, and we know knowledge is relevant if it reduces disaster risk (promoting an ethic of prevention), then citizen science is a subset of all development participation, but one with a troublesome relationship with equitable partnerships and empowerment. At the moment, citizen science initiatives more clearly reflect the experience and documentation of individual hazards rather than understanding the creation of disaster risk. There is compartmentalization into initiatives focused on individual hazards (**Figure 3**), or designed for specific 'moments' in the disaster continuum (**Figure 4**). This compartmentalization clearly reflects the specific goals of any one study, and it is important to recognize that the strong compartmentalization of our review papers is also a reflection of the academic audience intended for the peer-reviewed literature, but it signals the more focused immediate goals of citizen science in hazard settings. We contend that bringing together the core principles of citizen science with those of participatory DRR could create opportunities to address current challenges in DRR where future 'success' is defined against the reduction of future societal damages

FIGURE 3 | Treemap of hazard focus for citizen science for DRR projects.

associated with natural hazard. So, for example, with this framing it then becomes important to reconcile knowledge generated by multiple human perspectives (not strictly scientific knowledge) or inherent vulnerabilities as it is to describe single hazardous events. However, important conversations are needed about the comparative importance of empowerment and involvement measured against the value of the data generated toward reducing future risk, whether this is the politicization of citizen science, or encouraging the creation of scientific activism. The creation of these communities of practice requires space, time and, perhaps crucially, the curiosity of researchers themselves. The measure of success we develop below need not necessarily have been the primary goal of the studies reviewed here, but should some DRR benefit always be clear and transparent when working on and with communities at risk? It is not easy to bring different communities of practice together but the common goal or aim framed around the reduction of disaster risk could provide the momentum to generate these conversations and this analysis points to some of the gaps in evidence.

Stimulating Cross-Community Collaboration via an Evidence-Based Framework?

To further explore how a multi-dimensional framework centered around DRR might look in practice, we now consider the agreed principles from our project workshop. Participants here represented those with direct experience of citizen science initiatives, particularly in developing world and multihazard contexts, those from the knowledge tradition of participatory DRR, experts in technological citizen science (sensor design and remote sensing), hazard scientists and those with experience of narratives, nature writing and literary criticism. Our aim was to make these principles as simple but as comprehensive as possible.

The key argument that emerged was that through connecting and linking citizen science for DRR contexts, communities, methods and practices, we can improve our initiatives and also broaden the principles for effectiveness to include criteria of equity, justice, and empowerment.

Our project team developed six common key principles that determine a multi-dimensional citizen science project for DRR:

(1) Active benefits for all participants
(2) Clear attempts to ensure legacy and longevity
(3) Responsible engagement in both quiet times and during active hazard moments
(4) Framed around DRR goals
(5) Careful definition of partners (to ensure equitable outcomes)
(6) Equitable and empowering

These principles, which draw on a variety of knowledge traditions pertinent to DRR, are not designed to supersede the ten principles of citizen science developed by the European Citizen

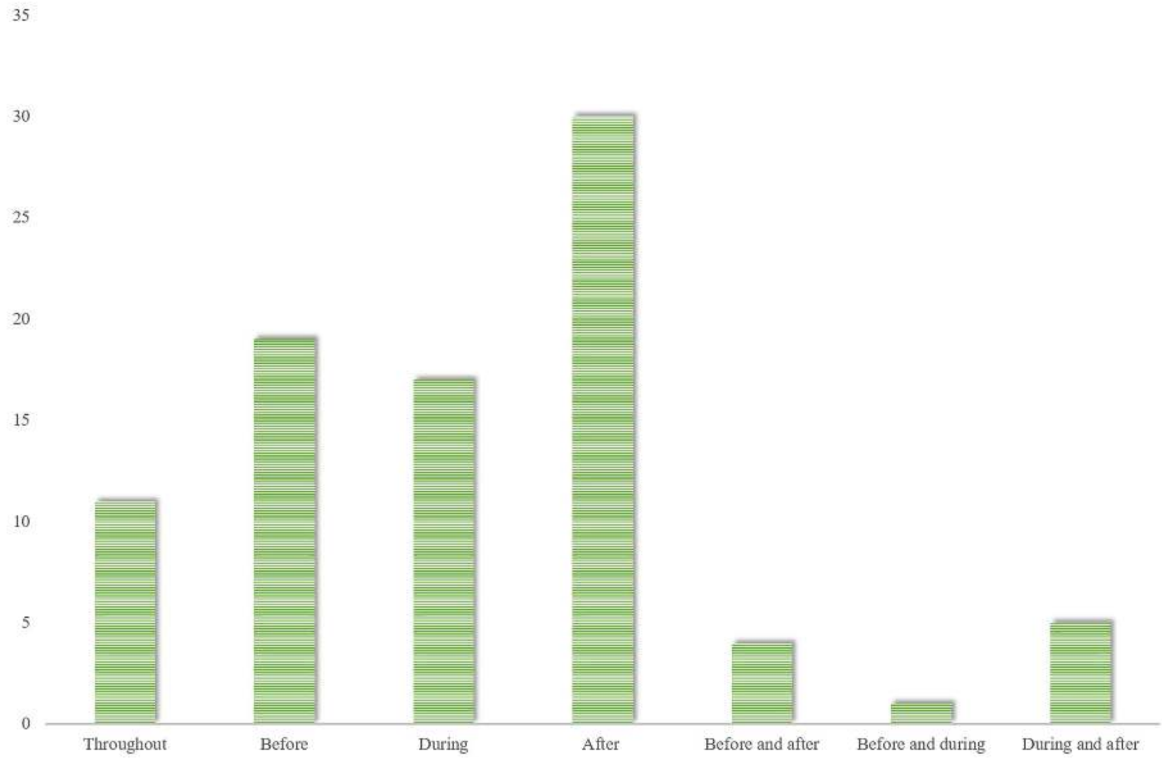

FIGURE 4 | Characterization of cases by stage of the disaster continuum.

Science Association (Robinson et al., 2018) but rather as exercise of consensus building around the particular case of citizen science for DRR. The addition of principles that speak to inclusion and empowerment was seen as important in contexts where data gathering might directly affect those who had experienced the trauma of the impacts of natural hazard. Nonetheless, some of the principles here are also more squarely aimed at generating success in the project and drew on direct experience, for example principle one is almost identical to ECSA's principle 3 (Robinson et al., 2018), and is borne of experience that without benefits for the scientists too, then projects can falter, while also speaking to a more normative rationale. Thus they include some of the broader aims associated with participatory DRR and broader participatory methodologies, and draw on knowledge of what drives success and good practice in broader citizen science initiatives. Where our principles diverge most clearly from the ECSA principles are around the use and definition of 'science outcomes.' Our broader definition of 'science outcomes' as 'new knowledge for DRR' enables a wider variety of research to be incorporated into this type of work. We also did not incorporate the ethical and legal dimensions of the work in our principles or explicitly consider good practice in evaluating and learning from citizen science (ECSA Principles 9 and 10, Robinson et al., 2018). However, our goal in converging on our principles was partly to create a framework against which we could understand how current practice measured against these principles and whether success was measured relative to the reduction of disaster risk either directly or tangentially (via, for example, improved knowledge of hazards). Is there an emerging evidence base for how to be successful? Where some principles were used, we wanted to evaluate the extent to which these helped to drive the success of the project in terms of tangibly reducing disaster risk. Thus, for each case study analysis we investigated who was conducting the citizen science project and how the interaction and data were gathered (see Methods and **Supplementary Materials**) and whether benefits to participants or equitable partnerships ensued. We also tried to understand the extent to which a citizen science project was deemed successful and how this success aligned with the reduction of disaster risk. None of the projects analyzed provided evidence for using all of the principles in any one project. Principles that were most frequently articulated were those around ensuring active benefits for participants and the careful definition of partners.

These results suggest that there is considerable opportunity to improve outcomes of citizen science in the context of DRR but a clearer framing of projects around these principles is necessary. Another striking feature is the extent to which studies in the literature report on the implementation and design phase of the research with rather less emphasis on the longevity or reflecting on the success of the project against original objectives. Thus, there is evidence that the principles of mutual benefits and empowerment are important but at the moment the evidence for how this ultimately creates success needs more work.

CONCLUSION

Citizen science, or the participation of 'non-specialists' in the gathering or analysis of scientific data, is playing an increasingly important role in scientific research. In the context of disasters, it is an excellent way for citizens to contribute to the forecasting and warning of hazards that impact them, and has great potential to be particularly helpful in low and middle income countries. In these regions, citizen science also has the potential to generate shared understanding of hazardous phenomena, improve communication and help communities at risk take actions to improve their resilience during and after hazardous events.

We conducted a global systematic mapping of citizen science for DRR projects in the academic literature, but 'opened up' our review to include projects that apply ideas and techniques that might more normally be associated with the social sciences and humanities as well as the traditional sciences. Our definition of citizen science in this context uses the word 'knowledge' instead of 'science' to define the landscape of DRR-focused citizen science projects across the world. This is because scientific, socio-scientific, cultural and political knowledge can all contribute to the reduction of disaster risk. Attempts to understand the crucial ingredients for success in citizen science also needs to draw on these knowledge traditions. It was beyond the scope of our research to include gray literature in our mapping and we recognize that further research is needed to truly 'open up' a review of citizen science for DRR to capture learning from projects published outside of peer-reviewed literature.

Our mapping identified 106 articles reporting on citizen science for DRR projects across the world. We identified: (a) geographic clusters (e.g., United States) and gaps (e.g., Africa), (b) a global predominance of earthquake and flooding-focused projects, (c) similar numbers of projects applying either crowdsourcing or participatory approaches and rather less applying methodologies from the arts and humanities, and (d) a post-event project majority. We also gathered information on the model of cooperation between scientist and citizen, and evidence for success in relation to our principles of citizen science. Based on our analysis, we conclude that interconnections between citizen science methods and practitioners are needed to strengthen and advance the field of citizen science, researchers and practitioners need to address the multi-dimensional nature of disasters and develop initiatives across the disaster continuum and, lastly, that principles and frameworks for evaluating citizen science initiatives are developed to tackle the challenges of ensuring equity, responsibility and empowerment of those most vulnerable to disaster risk. We identify scope for an international, transdisciplinary community of practice in citizen science for DRR to share lessons and inform grounded and relevant research in this field.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the **Supplementary Files**.

ETHICS STATEMENT

The research that produced this article was conducted in compliance with the University of East Anglia's Ethical Guidelines. The process included an expert workshop to which academics and practitioners with expertise relevant to the study were invited. Participants from outside the project consortium were informed of the aims of the research, including its publication goals, prior to consenting to take part and these aims were reiterated at the start of the workshop, this is in compliance with University of East Anglia's Ethical Guidelines, separate consent beyond consent obtained during the workshop was not necessary.

AUTHOR CONTRIBUTIONS

AH and JB led the conception and design of the manuscript, with input from JC and MH in the final stages. AH conducted the mapping and selected the studies, and with support from JB, JC, MA, PS, and KO, analyzed and extracted relevant information from the selected studies.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2019.00226/full#supplementary-material

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APPENDIX

Glossary (Based on UNISDR, 2018)

Disaster: A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

Disaster Risk Management: The application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses.

Disaster Risk Reduction: Is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development.

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

Preparedness: The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters.

Recovery: The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster affected community or society, aligning with the principles of sustainable development and "build back better," to avoid or reduce future disaster risk.

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.

Response: Actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.