



Invited perspectives: Building sustainable and resilient communities – recommended actions for natural hazard scientists

Joel C. Gill¹, Faith E. Taylor², Melanie J. Duncan³, Solmaz Mohadjer^{4,8}, Mirianna Budimir⁵, Hassan Mdala⁶, and Vera Bukachi⁷

¹Global Geoscience, British Geological Survey, Keyworth, NG12 5GG, United Kingdom

²Department of Geography, King's College London, London, WC2B 4BG, United Kingdom

³Multi-Hazards and Resilience, British Geological Survey, Edinburgh, EH14 4AP, United Kingdom

⁴Department of Geosciences, University of Tübingen, Schnarrenbergstr. 94-96, 72076 Tübingen, Germany

⁵Practical Action Consulting, Rugby, CV23 9QZ, United Kingdom

⁶Geological Survey of Malawi, Zomba, Malawi

⁷Kounkuey Design Initiative, Masera House, Kenyatta Market, P.O. Box 21972-00505, Nairobi, Kenya

⁸Earth and Environmental Sciences, University of Central Asia, 155 Qimatsho Imatshoev Street, Khorog, 736000, Tajikistan

Correspondence: Joel C. Gill (joell@bgs.ac.uk)

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Abstract. Reducing disaster risk is critical to securing the ambitions of the Sustainable Development Goals (SDGs), and natural hazard scientists make a key contribution to achieving this aim. Understanding Earth processes and dynamics underpins hazard analysis, which (alongside analysis of other disaster risk drivers) informs the actions required to manage and reduce disaster risk. Here we suggest how natural hazard research scientists can better contribute to the planning and development of sustainable and resilient communities through improved engagement in disaster risk reduction (DRR). Building on existing good practice, this perspective piece aims to provoke discussion in the natural hazard science community about how we can strengthen our engagement in DRR. We set out seven recommendations for enhancing the integration of natural hazard science into DRR: (i) characterise multi-hazard environments; (ii) prioritise effective, positive, long-term partnerships; (iii) understand and listen to your stakeholders; (iv) embed cultural understanding into natural hazard research; (v) ensure improved and equitable access to hazard information; (vi) champion people-centred DRR (leaving no one behind); and (vii) improve links between DRR and sustainable development. We then proceed to synthesise key actions that natural hazard scientists and research funders should consider taking to improve education, training, and research design and to strengthen institu-

tional, financial, and policy actions. We suggest that these actions should help to strengthen the effective application of natural hazard science to reduce disaster risk. By recognising and taking steps to address the issues raised in these recommendations, we propose that the natural hazard science community can more effectively contribute to the inter-/transdisciplinary, integrated work required to improve DRR.

1 Introduction

This paper considers how natural hazard research scientists can better contribute to the planning and development of sustainable and resilient communities through improved engagement in disaster risk reduction (DRR). We target natural hazard scientists with an interest in contributing to sustainable development and resilience building, but who are uncertain of what steps to take. Collectively we as authors represent organisations in academia, the public sector, and civil society with expertise from a range of countries and hazard settings. We reflect on existing good practice and identify how the natural hazard science community (including geologists, seismologists, volcanologists, hydrologists, meteorologists, physical geographers, geomorphologists) can strengthen the translation, adoption, and effective application of their under-

standing of physical processes and hazards to reduce disaster risk. While recognising the many debates relating to terminology, to inform the reader, we set out in Table 1 key terms and definitions used throughout this paper.

Natural hazards (e.g. landslides, earthquakes, floods) have a significant impact on lives, livelihoods, and economic growth, disproportionately affecting the most vulnerable in society and threatening development progress (Pelling et al., 2004). Between 1998 and 2017, disasters resulted in direct economic losses of USD 2908 billion, 1.3 million fatalities, and 4.4 billion people injured, rendered homeless, displaced, or needing emergency assistance (CRED/UNDRR, 2018). To achieve the UN Sustainable Development Goals (SDGs), we must accelerate efforts to reduce impacts and diverge from a “business as usual” approach (Spangenberg, 2016). The UN Sendai Framework for Disaster Risk Reduction (or “Sendai Framework”) aims to address this challenge, setting out a strategy to improve DRR (UNDRR, 2015).

While the Sendai Framework has a clear role for the natural hazard science community (Gill and Bullough, 2017), disasters are a complex and interdisciplinary challenge. Natural hazard scientists alone cannot provide the solutions necessary to ensure sustainable and resilient communities. The spatial and temporal occurrence of hazardous phenomena with exposure and vulnerability (both defined in Table 1) results in the generation of risk and potential for devastating effects. In this context, development challenges such as poverty, inequality, lack of access to and overconsumption of resources, climate change, and uncontrolled urbanisation can all drive changes to exposure and/or vulnerability, thus contributing to disaster risk (Pelling et al., 2004). Sustainable solutions require coherent engagement with diverse sectors and disciplines, including but not limited to the natural sciences. From our observations of research processes and collaborations within and beyond the international natural science community, we recognise some emerging trends, including more *interdisciplinary research* between the geosciences and the social sciences (Schlosser and Pfirman, 2012; Van Noorden, 2015; UKCDS, 2016; Stewart and Gill, 2017), such as that described in Hicks et al. (2014), Martinez et al. (2018) or Barclay et al. (2019), and increased emphasis on *international, cross-sectoral partnerships* (Carabine et al., 2015; UKCDS, 2016; Dodson, 2017), such as those facilitated by the UK Global Challenges Research Fund (UK Government, 2020).

These trends are positive and offer opportunities for natural scientists to enrich their research, embed it into policy and practice, and help deliver development impact.

Building on existing good practice, this perspective piece therefore aims to provoke discussion in the natural hazard science community about how we can make the most of these opportunities and strengthen our engagement in DRR. In Sect. 2, we set out seven recommendations for improving the integration of natural hazard science into DRR. In Sect. 3, we synthesise key actions that natural hazard scien-

tists and research funders can take to improve education and training, research design and methods, and partnerships and practice. In Sect. 4, we summarise some of the key benefits to the natural hazard community and conclude that by taking specific steps, the natural hazard community can better contribute to interdisciplinary, integrated work to improve DRR. We acknowledge that not all natural hazard scientists need to work across all the proposed areas and that there is a clear requirement for disciplinary specialism. However, it is critical for natural hazard scientists to be aware of the broader DRR landscape and opportunities for co-benefits to both the natural hazard community and society through enhanced ways of working.

By recognising and taking steps to address the issues raised in these recommendations, we propose in Sect. 4 that the natural hazard science community can more effectively contribute to the inter-/transdisciplinary, integrated work needed to improve DRR.

2 Seven recommendations to ensure natural hazard science supports effective disaster risk reduction

2.1 Characterise (multi-)hazard environments

Understanding disaster risk, the first *priority for action* within the Sendai Framework, includes the need to understand hazard characteristics and the natural environment (UNDRR, 2015). Ongoing geoscience research into surface and subsurface processes and the resultant formation of natural hazards remains essential. To better support DRR, however, we should consider in a comprehensive and systematic manner the range of hazard types, multi-hazard relationships, and hazard scales that could occur in any given region and how this hazard landscape may change over time. Many communities around the world are exposed to multiple natural hazards, which do not always occur independently (Kappes et al., 2012). Relationships between hazards may exist that generate chains or networks of hazards (Gill and Malamud, 2014; Duncan et al., 2016; AghaKouchak et al., 2018).

Understanding the multi-hazard landscape of a region gives a better understanding of risk and can help to inform management priorities, ensuring actions taken to reduce vulnerability to one hazard do not inadvertently increase vulnerability to others, while not ignoring the impacts of consecutive disasters (Tobin and Montz, 1997; ARMONIA, 2007; Kappes et al., 2010; de Ruiter et al., 2020; Gill et al., 2020). Whilst work is being undertaken towards this objective, a single-hazard approach to research and dissemination is still dominant (Ciurean et al., 2018). This can result in technical excellence with respect to single-hazard research but hinders cross-disciplinary learning and reduces multi-hazard dialogue.

Literature describing approaches to understand multi-hazard relationships is limited, often focused on simulated

Table 1. Key terms and definitions used throughout this paper.

Term	Definition	Source
Culture	The complex whole which includes knowledge, beliefs, arts, morals, laws, customs, and any other capabilities and habits acquired by a human as a member of society.	UNESCO (2017)
Exposure	The situation of people, infrastructure, housing, production capacities, and other tangible human assets located in hazard-prone areas.	UNDRR (2017)
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.	UNDRR (2017)
Interdisciplinary	Interdisciplinary studies address specific real-world problems. This involves bringing people and ideas together from different disciplines (e.g. natural and social scientists) to collectively frame a problem, agree on a methodological approach, and analyse data in an integrated manner.	Adapted from Hammer and Söderqvist (2001) and Stock and Burton (2011) (see references therein)
Partner	A “partner” is a person, organisation, network, or association who works collaboratively with others as part of a defined agreement, project, or framework to achieve a common purpose or undertake a specific task and to share risks, responsibilities, resources, competencies, and benefits.	UNDRR (2016)
Positionality	The stance or positioning of the researcher in relation to the social and political context of the study – the community, the organisation, or the participant group.	SAGE (2014)
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.	UNDRR (2017)
Stakeholder	Any individual or group with an interest in reducing disaster risk (i.e. including those within a project and external to but benefiting from a project).	UNDRR (2016)
Transdisciplinary	Transdisciplinary studies go beyond interdisciplinary studies by placing emphasis on the participation of non-academic partners to solve real-world problems, by differentiating and integrating knowledge from various scientific and societal bodies of knowledge.	Adapted from Stock and Burton (2011) (see references therein) and Lang et al. (2012).
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.	UNDRR (2017)

environments and combinations of two hazards, rather than methods examining real multi-hazard environments exposed to interrelating hazards (Ciurean et al., 2018). Understanding multi-hazard risk requires new approaches to knowledge infrastructures (i.e. the networks of people, institutions, and processes concerned with the world’s knowledge), data collection and management, database structure, and hazard modelling to understand case histories and potential future

scenarios of risk. For example, databases that record losses from disasters could be adapted to reflect the multi-hazard nature of the hazards involved and improve attribution of disaster losses to specific processes within this multi-hazard disaster (e.g. Froude and Petley, 2018). In terms of training and organisational management, we propose that more space (e.g. physical office space, space on a curriculum) should be dedicated to working across disciplines and identifying the

connections between single hazards. Hemingway and Gunawan (2018) and Golnaraghi (2012) outline principles and successful examples of multi-hazard partnerships at the national level.

New approaches to data collection are needed to better characterise multi-hazard environments. These include consideration of different scale events, ensuring that low-magnitude, frequent events are considered. Smaller magnitude events and their impacts are often not recorded because they are below the resolution of recording methods (Guzzetti et al., 2012) or do not qualify as an “event” due to an imposed threshold (Gall et al., 2009). Yet, particularly in the Global South (so-called “developing countries”), the cumulative impact of these small, frequent hazards (also known as “extensive hazards”; UNDRR, 2009) can outweigh the impact of larger events, as well as erode the coping capacity of communities when high-magnitude events do occur (Bull-Kamanga et al., 2003). The integration of data from diverse sources (e.g. fieldwork, published literature, grey literature, interviews to capture local perceptions of hazards, and questionnaires) can help to more fully understand the hazard environment. Examples include the DesInventar database, which primarily collects records from local newspaper archives to investigate events where only a small number of people were affected (Satterthwaite et al., 2018). Compiling detailed databases is time consuming but provides a more complete body of evidence to understand the full characteristics of hazards affecting a region and a more accurate spatial pattern of mortality and morbidity (Osuteye et al., 2017).

Another important approach to data collection that enriches understanding of the multi-hazard environment and extensive events is citizen science. Hicks et al. (2019) note citizen science to be “the participation of people from outside professional organisations in the gathering or analysis of scientific data” and present a systematic global mapping of citizen science used for DRR. This review shows how citizen science can generate shared understanding of hazardous phenomena. In the example of Jacobs et al. (2019), a network of observers in Uganda helped collect and share data on eight different hazards, contributing to greater understanding of extensive hazards impacting people in the region.

The hazard environment is not static but can change due to natural forcing or anthropogenic activity, including climate change. Such processes can change the likelihood of natural hazards occurring, as well as hazards triggering or catalysing other hazards (Gill and Malamud, 2017; AghaKouchak et al., 2018). For example, road construction can increase the likelihood of landslides being triggered during an earthquake or heavy rain (Montgomery, 1994; Owen et al., 2008). Long-term studies of dynamic landscape changes due to anthropogenic activity are often beyond the life cycle of research projects. Such studies may require different ways of working, such as establishing partnerships with organisations with a long-term presence in an area.

Suggested actions/priorities for change are as follows.

- In both training and operational settings, space should be dedicated to working across disciplines to identify a fuller range of hazards and their potential interactions (or coincidence in time).
- New ways to collect data on, and analysis of, multi-hazards are needed, progressing from the consideration of two hazard types in simulated scenarios to multiple hazard types in real-world contexts (Ciurean et al., 2018).
- Enhanced communication across disciplines can help to facilitate dialogue relating to risk from multi-hazards. We encourage leadership from geoscience unions, research funders, and professional associations to facilitate more cross-hazard cooperation through joint meetings and collaborative working spaces.

2.2 Prioritise effective, positive, long-term partnerships

Reducing disaster risk requires generating and utilising knowledge from across disciplines and sectors (UNDRR, 2015; Twigg, 2015). Recognition of the complexity of risk has led to an increase in calls for and application of interdisciplinary partnerships to disaster risk and resilience research, integrating natural and physical science knowledge, methods, and/or approaches with the social sciences, arts, and humanities. While natural hazard scientists do not need to become social scientists (or vice versa), greater engagement with the social sciences can help them to sit their work in its societal and political context, strengthening work and its impact. Donovan et al. (2011) note that for a geoscientist, interdisciplinarity requires learning “the customs and language of a foreign discipline, reading, exploring and absorbing social science methodologies and theories”. Fundamentally, this requires flexibility, the willingness to listen and do things differently, and respect for differences.

The drive to link research to practice and the participation of “non-scientists/specialists” in the design and implementation of disaster risk science (transdisciplinary research practice; Horlick-Jones and Sime, 2004; Hilhorst and Heijmans, 2012) calls for strong partnerships. This acknowledges the need to work with those at risk rather than viewing them as research “subjects” or “recipients” (Pelling, 2007). This can have many benefits, including helping to increase the visibility of preventative measures to communities at risk. Citizen science is one way by which those at risk can be part of the research team, requiring frameworks to consider issues of equity, justice, and empowerment to ensure effective, positive, long-term partnerships (Hicks et al., 2019).

Partnerships, emphasised in the Sendai Framework targets and guiding principles, are key to harnessing knowledge, to better understand and address the problems faced by those at risk (see Sect. 2.3). Partnerships can be of many different kinds (including networks and collaborations) and when established effectively, they can increase the impact of DRR

initiatives by ensuring their sustainability, replicability, and better use of resources (Twigg, 2015). Partnerships can be both vertical (global, regional, national to local) and horizontal (across sectors and disciplines) (Twigg, 2015). Existing connections are often the best starting point; the Sendai Framework recommends that science contributions to DRR can be enhanced through the coordination of existing networks and scientific institutions at all levels and regions (UN-DRR, 2015). Networks can create an enabling environment for knowledge sharing, development, and technology transfer (Šakić Trogrlić et al., 2017). For example, the Global Volcano Model network successfully coordinated the input of > 130 scientists for the first review of volcanic hazards and threats in the 2015 Global Assessment Report (Loughlin et al., 2015). The ongoing UK Global Challenges Research Fund (GCRF) project, Tomorrow's Cities, aims to enhance risk-sensitive urban development through a global network of integrated research programmes, led by local teams in low- to middle-income countries (Tomorrow's Cities, 2020).

Although essential, partnerships can be difficult to establish and maintain. They take time, negotiation, sustained effort, transparency, trust, resources, commitment, and institutional support (Twigg, 2015). Ensuring researchers understand their role in DRR policy and practice, and likewise the role and responsibilities of partner institutions, underpins effective, equitable, and trusting partnerships. Similarly, recognising the distinction between those institutions with operational mandates and those undertaking research is critical to ensuring that research supports, rather than undermines, national and local capacity (see Newhall et al., 1999).

The ELRHA Guide to Constructing Effective Partnerships (ELRHA, 2012) provides a useful overview of the benefits and challenges of collaborations between humanitarian and academic organisations and provides practical guidance on identifying, establishing, and maintaining effective partnerships. Generic guidance on how individual academics and organisations build more effective partnerships with, for instance, national science institutions outside of their own country is not common. An initial step would be to see whether any internal policies exist to support this, such as guidance for working overseas (e.g. obtaining research permissions), data management policies (e.g. data sharing and intellectual property rights), and ethics policies and frameworks. The co-establishment of memoranda of understanding, including codes of practice and ethics, can form the basis for effective, lasting institutional partnerships; they are underpinned with funding to support the individuals sustaining these partnerships. Documenting effective partnership examples (and any challenges) and sharing these with the wider research community would also benefit those researchers new to building networks and collaborations.

Suggested actions/priorities for change are as follows.

- Build partnerships with a range of social scientists to help put natural hazard science in its broader societal context.
- Higher education and ongoing professional development training should include partnership development topics (e.g. project management, facilitation skills, and inter- and transdisciplinary working).
- Natural hazard scientists should implement ethical frameworks for building and maintaining equitable partnerships (see Conway and Waage, 2010).
- Funding opportunities should recognise, and provide for, the time and resources required to build partnerships (e.g. attend in-person meetings or conferences), with this contributing to capacity strengthening. Where remote working is required, virtual communication tools, social media, and fora such as groups on ResearchGate (2020) can initiate dialogue. Consideration should be given to those who might be missing from these partnerships and how they could be engaged through the project.
- Institutional support for partnerships, through Memoranda of Understanding between institutions, for instance, can ensure mutually agreed expectations, codes of practice, and ethics. Roles and responsibilities within partnerships should be discussed and clarified. One project management approach is to use a RACI diagram (see <https://pmdprostarter.org/raci-diagram/>, last access: 7 May 2020), capturing information on key responsibilities, accountabilities, whom should be consulted, and whom should be informed.
- Funding for researchers should be based in the region of study to help strengthen both knowledge exchange and sustainability of the impact.

2.3 Understand and listen to your stakeholders

Understanding the priorities, interests, ambitions, and challenges of stakeholders is essential to developing and undertaking effective DRR research. Stakeholders might include different researchers across many disciplines, government agencies, non-governmental agencies, civil society, the private sector, and communities at risk (Twigg, 2015). Stakeholder mapping (identifying and understanding stakeholders in a given project and how they sit within and influence a system) is an important task when connecting natural hazard science to DRR, although a significant undertaking. There are many tools to support this process, with one illustrated in Fig. 1. Stakeholder mapping identifies the relative interest and influence of stakeholders throughout the project life cycle, thereby allowing the project team to focus and adapt their engagement during the project. Stakeholder mapping

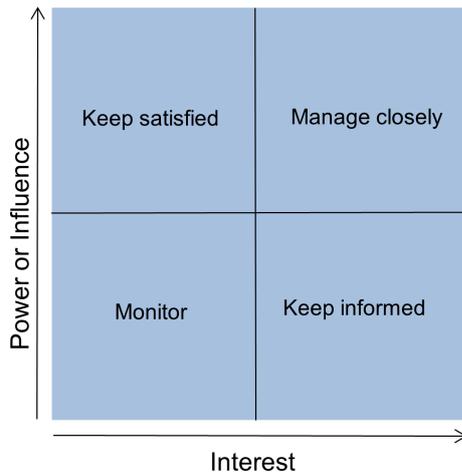


Figure 1. Stakeholder mapping tool. Determining the level of interest and influence (or power) of different stakeholders can help to ensure effective communication with each group. Figure adapted from Mendelow (1981).

may help identify potential partners (Sect. 2.2), or existing partners may assist in identifying who the stakeholders are.

Consultation with stakeholders should help inform the types of research activities undertaken. There are numerous examples where a hypothesis, or a proposed solution, transpires not to be a stakeholder priority, and thus research outputs struggle to gain traction (Clot, 2014; Schipper and Pelling, 2006). The Sendai Framework advocates for opportunities for Global South nations to identify and express their needs and priorities and for countries in the Global North (so-called “developed countries”) to actively listen to them (UNDRR, 2015). Asking stakeholders “what is important to you?” can open up new ideas and avenues of effective collaboration. In Malawi, Leck et al. (2018) highlight how international non-governmental organisations (NGOs) had set the agenda for local DRR, undermining the authority of local governments. To solve problems that are both scientifically novel and societally relevant, it is key to have awareness of local context (political, economic, social, cultural, technological, legal, and environmental) and local perceptions of risk through meaningful engagement and co-production of research with stakeholders.

Rather than starting research with systematic data collection to test a hypothesis, time may be better devoted to the development of a research question that is informed by stakeholder needs and an understanding of local context. For example, instead of beginning with the aim of developing a GIS model for visualising earthquake risk, more effective research may commence by investigating who manages earthquake risk, how this is done, what scientific and organisational challenges they face (e.g. which stakeholders are involved, what other priorities do they have, and what other constraints exist on their time), and what their technical,

time, and scientific capacities are to develop and adopt new ways of working. Ideally, the project’s aims and hypothesis would then be developed in collaboration with stakeholders. Ensuring partners from the Global South (e.g. researchers, NGOs) are co-investigators on research proposals can bring contextual understanding into project design and implementation. Ongoing conversations and assessment of prototypes may be needed to help stakeholders articulate their needs and help researchers understand what research and methods are relevant, over time and through careful management of this important relationship. This dialogue and the emerging contextual understanding can guide more effective hypothesis development and data collection.

“Theory of Change” (Weiss, 1995) is one approach that could enable this co-production, with resources available online (e.g. DIY Toolkit, 2020). Theory of Change starts by using a context analysis to identify the problem to be solved (e.g. reducing deaths from tsunamis) and then works backwards to characterise root drivers of this problem (e.g. ineffective early warning systems), the key audiences for implementing change (e.g. civil protection and community groups), the access points and motivators for those groups, steps required to bring about change, and the broader benefits. At each stage, the Theory of Change approach gives attention to uncertainties and assumptions. Di Baldassarre et al. (2018) noted that societal responses to risk reduction measures can produce unintended consequences. Reflective Theory of Change approaches, combined with an appropriate monitoring programme, can also be used to identify potential unintended negative consequences arising from particular activities or recommendations and determine appropriate mitigation steps.

Practitioners, donors, and academics have applied Theory of Change effectively in different ways (Vogel, 2012), helping to identify key stakeholders and create a roadmap to achieve real change through applied research. While time consuming and often challenging to follow within the typical cycle of funding applications, this approach can be fundamental to developing research programmes that result in improved DRR.

Suggested actions/priorities for change are as follows.

- Higher education and ongoing professional development training should cover stakeholder mapping, managing people in projects, facilitation skills (including running workshops), and transdisciplinary working.
- Training should take place for natural hazard scientists on how to ethically identify stakeholders and co-produce research questions using techniques such as Theory of Change.
- Develop long-term relationships with applied partners such as NGOs and national institutions (e.g. geological surveys, hazard monitoring agencies) who have a long-term presence in and access to a range of stakeholders.

- Mechanisms should exist (e.g. funding for time and networking) to include non-academic partners and stakeholders in research proposals, co-develop transdisciplinary research questions, identify desired outputs, and understand stakeholder capacities.

2.4 Embed cultural understanding into natural hazard research

Culture, defined in Table 1 (but we recognise other definitions exist), includes the social institutions, customs, and beliefs that people hold, as well as the characteristics that unite people (Cannon and Schipper, 2014). Examples include religious beliefs, traditional beliefs, values, livelihood choices, and settlement patterns (Canon and Schipper, 2014). We are part of and affected by culture as researchers, and this can shape the way in which we approach ideas or partnerships as natural hazard scientists. Culture can also affect risk, by either increasing or reducing the vulnerability of individuals and communities, shaping the norms by which the acceptability of risk is defined, and influencing how people respond to and cope with disasters (Bankoff, 2003; Schipper and Dekens, 2009; Canon and Schipper, 2014; O’Connell et al., 2017). Examples include the following.

Indigenous knowledge and culture are attributed to the very high survival rate following the 26 November 1999 tsunami on Pentecost Island, Vanuatu (Walshe and Nunn, 2012).

The cultural expectation that women are caregivers was shown to increase the physical exposure of women to illness and the psychological burden post disaster in Manila, Philippines (Reyes and Lu, 2016).

Local sub-cultures at Merapi volcano, Indonesia, were found to influence local community actions during frequent eruptions (Donovan et al., 2012).

Understanding culture is therefore important when considering how to reduce disaster risk. The Sendai Framework notes that DRR policy and practice should integrate cultural perspectives and advocates for the creation of “cultures of prevention” (vs. response) and maintenance (vs. disrepair which can increase physical vulnerability) to be established (UNDRR, 2015). Therefore, natural hazard scientists should not only understand how culture relates to disaster risk response and reduction, but may also need to work with experts in the social sciences and humanities to help drive changes in established cultures. Understanding culture is a critical part of the context analysis described in Sect. 2.3, done before research, and will require the strong partnerships advocated for in Sect. 2.2. While ethnographic research (i.e. immersion in a group for an extended period, observing behaviour, listening to what is being said, and asking questions; Bryman, 2016) to understand people and their cultures is not part of natural hazard science training, the outcomes of such research could enhance the work of natural hazard scientists and help to maximise the impact. Examples include the following.

- *Enriching data.* Our understanding of historical occurrences of natural hazards informs our characterisation of the potential for future events and their likely magnitudes. Natural hazard science has traditionally understood past events through historical archives, instrumental records, and field observations. Understanding culture is critical to identifying how information is better captured and communicated in any given location. Stories passed down from one generation to another, for example, may be a significant record of information and help to enrich data collected using traditional fieldwork and in locations where written and instrumental records are minimal (Cronin and Cashman, 2008).
- *Contextual understanding.* Understanding cultural beliefs, practices, and rituals can also help researchers to be sensitive to the associations people have with hazardous areas (e.g. the religious significance of a volcano), as well as understand their coping capacities and resilience of communities living in hazardous areas (e.g. Cronin et al., 2004).
- *Improving research dissemination.* Many grant applications require participants to outline research impact on society and how information will be disseminated to stakeholders. Dissemination should be done in a way that is acceptable and understandable to stakeholders (Sect. 2.3), which will vary (e.g. regionally). Understanding culture can help to guide decisions about the appropriate nature of research outputs (e.g. storytelling, radio shows, briefing notes, films, theatre; e.g. Hicks et al., 2017) and who is best placed to share these.

Natural hazard scientists sit within their own cultures, and this positionality (defined in Table 1) is likely to affect their approach to research and interactions with others. Researcher positionality could be integrated into the training of hazard scientists. For example, before a researcher engages in work in an unfamiliar or different cultural context to their own, they should reflect on how their experiences, values, and beliefs could influence or prejudice whom they may consult, the questions they may ask, data they gather, “products” they advocate for, and appropriate conduct. Individual perspectives on religion, for example, may mean a researcher is reluctant to collaborate with leaders of faith-based organisations. Analyses of the 2014–2016 Ebola crisis in Sierra Leone, however, demonstrate that faith leaders can play a transformational role in communicating key humanitarian messages (Featherstone, 2015). Likewise, positionality includes consideration of the assumptions that might be extended to researchers by stakeholders and participants, particularly around issues of trust and equality. Being aware of the implications, for instance, of being a researcher from a high-income country working in a low-income country, in terms of stakeholder expectations is critical.

Suggested actions/priorities for change are as follows.

- When developing research partnerships, natural hazard scientists should consider including those with ethnographic training (e.g. geographers, historians, and anthropologists), or identify existing and relevant ethnographic knowledge in publications and reports.
- When planning research dissemination strategies, public outreach, and hazard education initiatives, in addition to their partners and stakeholders, natural hazard scientists could consult literature, historians, anthropologists to understand cultural constraints, challenges, and opportunities.
- Train natural hazard scientists to understand and reflect on their own positionality, providing them with the skills to understand how their belief systems may influence their work.

2.5 Ensure improved and equitable access to hazard information

Hazard information should reach those in need, be understood, and be acted on if it is to help reduce risk (Mohadjer et al., 2016). This requires the gap between knowledge generation and knowledge access to be addressed (Aitsi-Selmi et al., 2016). It is often those most vulnerable to the impacts of disasters who struggle to access useable hazard information. The natural hazard science community should consider not only equitable access, but also how to ensure that all stakeholders can act on hazard information. As demonstrated in Sect. 2.2–2.4, working in partnership, listening to stakeholders, and culturally contextualising research can help to create useful hazard information. Citizen science approaches can further bridge the gap between knowledge generation and access (Jacobs et al., 2019). Table 2 further outlines the many factors that can enhance access to hazard information.

Natural hazard scientists should be aware of and sensitive to any barriers if they are to deliver information in an appropriate form, a timely manner, and a way that facilitates action by stakeholders (Scienseed, 2016). Training for hazard scientists could draw on good communication practices to strengthen their ability to make natural hazard science more accessible to groups outside of the professional community. Consideration should be given to the audience and their needs, including (amongst other characteristics) their values, attitudes, concerns, knowledge, language, and personal and social aspirations (Liverman, 2008). Scientists who wish to inform decision making should use this understanding to tailor information to their audience's specific needs. Useful hazard information also takes into account the technical limitations of data. For example, the most common assessment methods for seismic hazard are probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analysis (DSHA). Though useful for developing building codes, PSHA may be misleading in locations where data

are sparse (Stein et al., 2018), and other methods may be required (Robinson et al., 2018).

Natural hazard scientists should therefore work collaboratively with partners and stakeholders to develop hazard information products with their intended audience. The most effective method of understanding informational needs of stakeholders is to establish and nurture a two-way communication, co-production, between scientists and decision-makers, building relationships, trust, and credibility over time (Morss et al., 2005). This dialogue will help to guide the choice of language and content of hazard information products to make them more appropriate for stakeholders. This includes the spoken language, but also the terminology and level of understanding of the content pitched at stakeholders.

Suggested actions/priorities for change are as follows.

- Natural hazard scientists should pursue open-access publishing, and/or write short, accessible summaries of their research (e.g. policy briefs) to be disseminated to appropriate stakeholders.
- Good communication practice should be essential training for natural hazard scientists, exploring the importance of understanding and tailoring information to specific audiences, and co-developing hazard information products with intended audiences.
- Working with partners and stakeholders (co-production) is key to the creation of useable hazard information.

2.6 Champion people-centred DRR – leaving no one behind

The SDGs and Sendai Framework both emphasise “leaving no one behind” and ensuring that the poorest and most vulnerable in society have access to the resources, information, and support required to effectively reduce risk and encourage sustainable development. People's ability to prepare for, respond to, and recover from disasters is shaped by an array of social, cultural, economic, and political factors (Wisner et al., 2012). Vulnerability to hazards is exacerbated by existing social stigmatisation and isolation, and those who are marginalised in society are often the most vulnerable in facing natural hazards (Pincha, 2008; Wisner et al., 2012; Gorman-Murray, 2018). For natural hazard scientists, this means acknowledging that risk reduction is not simply about the hazard, but also the analysis and understanding of vulnerability (often the weaker component of risk analysis; Schneiderbauer et al., 2006) and actively reflecting upon where we work, with whom we work, and how we work. This may involve consideration of our own positionality (outlined in Sect. 2.4) in terms of how we understand marginalised groups. It also requires informed and difficult decisions, balancing the choice to work in areas where some marginalised groups are located (e.g. fragile states, regions with active conflict, and regions where humanitarian workers are threatened), against whether and how natural hazard

Table 2. Accessibility and usability of hazard information.

Theme	Challenges to accessibility and usability of information	Actions to improve accessibility and usability of information.
Communication medium	Differential access to and control over communication technology (the “digital divide”) is a barrier to reaching some marginalised groups, including women, in many parts of the world (GDN, 2009; Shrestha et al., 2014).	Multiple communication media to reach multiple vulnerable groups.
Open access	Many natural hazard reports, maps, databases, and tools exist behind paywalls, with access limited to those who can pay.	Publishing in open-access formats can make access, usage, and dissemination of data less time-consuming and resource-intensive (Mohadjer et al., 2016).
Language and content	Information may not be accessible if it is not appropriately tailored for an audience to understand and make decisions from.	Carefully explaining technical language, utilising diverse methods for communicating concepts such as uncertainty, publishing in appropriate local languages, considering literacy levels, and providing advice on specific actions to take to mitigate risks from natural hazards.
Capacity of hazard scientists to communicate	Access to hazard information often depends on natural hazard scientists being proactive at disseminating beyond traditional scientific journals.	Additional training, beyond the scope of many traditional geoscience courses, to increase confidence in using different dissemination methods.
Resource availability	Those who have access to information (e.g. hazard professionals) may not have the resources needed to share this information with those who do not have access (e.g. the general public).	Increased and better partnerships (Sect. 2.2), to help leverage the resources needed for effective communication.
Timeliness of information	There may be a difference between when hazard information is needed and when it can actually be generated (Robinson et al., 2018).	Long-term, sustained partnerships (Sect. 2.2) can help to generate useful outputs rapidly by drawing on existing understanding of stakeholders and their needs and capacities.

scientists can safely, ethically, and effectively work in these regions.

Marginalised groups risk being excluded from all aspects of DRR, including understanding hazards and risk. In a study of flood management in Jakarta, van Voorst and Hellman (2015) found that strategies to increase rainfall infiltration in open spaces had been ineffective due to these spaces being occupied by marginalised groups who did not appear on the official city map. This example highlights how the uncertainties and politics of information used in a seemingly “neutral” hazard assessment may have unanticipated outcomes. Proactive effort is recommended to reach out to, collaborate with (including through citizen science initiatives), and listen to the voices of marginalised groups, with careful consideration of which voices are missing (Brown et al., 2019), starting with stakeholder identification (Sect. 2.3). Marginalised groups may be more vulnerable to disasters, but they also have valuable knowledge, skills, experiences, and coping methods that should not be overlooked or ignored.

Leaving no one behind also means better engagement with indigenous communities and integration of local and indige-

nous knowledge and perceptions into disaster risk reduction. Environmental history, passed between generations through storytelling, can be an important source of information (see Sect. 2.4), enriching the data used to understand the multi-hazard landscape of a region (see Sect. 2.1). Approaching the topic of local knowledge requires designing fully participatory approaches to reflect its heterogeneity, in terms of both content and distribution within the community (Šakić Trogrlić et al., 2019). Mercer et al. (2010) set out a framework to integrate indigenous and scientific knowledge for disaster risk reduction. Such approaches, and an exploration of their strengths and criticisms, are not typically included in the curricula of subjects training natural hazard scientists (e.g. Earth science). This may hinder the extent to which natural hazard scientists accept the validity of local and indigenous knowledge, proactively engage with this as a source of evidence, and integrate it into hazard assessments. Other groups at risk of being left behind are children and youth, with themes relating to natural hazards and disaster risk often not included in the school curricula for those in the Global South.

Suggested actions/priorities for change are as follows.

- Increase reflection on *how* natural hazard scientists ensure meaningful participation in research and outreach activities by underrepresented, vulnerable, and marginalised groups.
- Include training on integrating local and indigenous knowledge into natural hazard assessments and disaster risk reduction.
- Introduction of natural hazard and DRR-related topics in the curriculum at lower education levels.

2.7 Improve links between DRR and sustainable development

DRR can drive forward and protect development progress and is therefore embedded within 10 of the 17 SDGs. Goals on poverty, hunger, health, education, water and sanitation, infrastructure, cities, climate change, oceans, and terrestrial ecosystems all refer to risk reduction, building resilience, early warning, or adaptation (United Nations, 2015). Furthermore, effective sustainable development interventions (e.g. addressing inequalities, increasing access to resources, better planned urbanisation) can increase individual, community, institutional, and infrastructure resilience by reducing exposure and/or vulnerability (Pelling et al., 2004). Examples of both relationships include the following.

- *SDG 11 (sustainable cities)*. Embedding understanding of the subsurface (e.g. geotechnical properties, shallow geohazard potential) into urban planning can increase the safety of urban development (Mielby et al., 2017).
- *SDG 4 (quality education)*. Increasing access to education can reduce vulnerability to natural hazards by increasing understanding of Earth dynamics and environmental change and exploring steps to reduce risk (Mohadjer et al., 2020).

While there is a growing awareness of the relationship between DRR and sustainable development, it is not yet clear whether this is embedded within the natural hazard community. Gill and Bullough (2017) noted that only 19 of 1059 sessions at the 2017 European Geoscience Union (EGU) General Assembly referred to the SDGs, Sendai Framework, or Paris Agreement. Furthermore, of the 1268 abstracts submitted to sessions within the Natural Hazards Division of the 2019 EGU General Assembly, only two referred to “sustainable development”. Based on a Google Scholar search (18 November 2019), of 697 articles published in the EGU journal *Natural Hazards and Earth System Sciences* between 2015 and 2018, 35 (5%) make direct reference to sustainable development. Whilst acknowledging that some studies may be contributing to sustainable development through other research outputs, what these statistics suggest is that some natural hazard scientists may be missing opportunities

to address research questions of local/national priority expressed through relevant development strategies (e.g. Kenya Vision 2030). This is increasingly a demand made by research funders; for example, it is embedded within the UK Global Challenges Research Fund strategy (UK Government, 2020). Aligning research power with sustainable development ambitions expressed in these strategies can help to secure critical “pathways to impact” that help to embed natural hazard research into risk reduction and embed risk reduction into sustainable development. The integration of DRR into sustainable development policy and practice could also help increase the visibility of preventative measures among decision makers. As Di Baldassarre et al. (2018) note, examples of risk reduction measures that have had a positive impact are an important source of learning. Mainstreaming these in collective learning documents such as voluntary national reviews (on progress towards the SDGs) can help build recognition of the value of particular measures.

Translating natural hazard science into tools that support sustainable development policy and practice requires sustained and effective dialogue (Lubchenco et al., 2015). This may require new partnerships (see Sect. 2.2) and communication methods (Marker, 2016; Stewart and Gill, 2017), to strengthen coherence between different policies, to mainstream DRR, and to avoid a policy in one sector increasing vulnerability to natural hazards. The importance of policy coherence is embedded within the SDGs (United Nations, 2015), and articulated as being critical to climate change adaptation (England et al., 2018).

Suggested actions/priorities for change are as follows.

- Increase awareness of how individual natural hazard research projects join up and relate to regional, national, and local sustainable development, disaster risk reduction, and disaster risk management strategies.
- Embed training in public policy into natural hazard science courses at the university level.

3 Discussion and cross-cutting themes

In Sect. 2, we reflected on seven ways those working on natural hazard science can enhance their contribution to DRR, integrating examples of good practice and innovative solutions where appropriate. In Table 3, we synthesise priorities for change proposed in Sect. 2.1 to 2.7, grouping these into changes linked to (i) education, training, and continued professional development; (ii) research priorities, methods, and approaches; and (iii) institutional, financial, and policy actions. Each of these would benefit from aligned funding.

Whilst the seven recommendations could be conceived as utopian, we have provided some practical steps that build on the existing skills and strengths of natural hazard scientists. In addition, we have identified where enablers, such as training programmes and funding, are required. Action to

Table 3. Summary of action points to help improve engagement of natural hazard scientists in DRR.

Recommendations	Suggested actions		
	Education, training, and continued professional development	Research design, methods, and implementation	Institutional, financial, and policy actions
Characterise (multi-) hazard environments	In training, space for enhancing communication and working across disciplines.	Improve methods to capture and document multi-hazard observations. Improve analysis of multi-hazard environments.	More cross-hazard cooperation through joint meetings and collaborative working spaces.
Prioritise positive partnerships	Include formal training in ethical and equitable partnership development.	Build partnerships with a range of disciplines and groups to help put natural hazard science in its broader societal context. Discuss and agree roles and responsibilities within partnerships.	Develop funding mechanisms to build and maintain long-term partnerships and include non-academic partners in research proposals. Increase opportunities for networking to facilitate partnership building (particularly for early career scientists). Implement frameworks for ethical and equitable partnerships.
Listen to and understand stakeholders	Train natural hazard scientists in stakeholder mapping, co-production of research questions, and techniques such as Theory of Change.	Ensure research questions are driven by an understanding of local context, perceptions, and stakeholder needs.	Develop long-term relationships with applied partners such as NGOs and the public sector.
Embed cultural understanding into natural hazard research	Train natural hazard scientists to understand and reflect on their own positionality.	Broader research project teams and greater engagement with social science communities and/or literature.	Consult relevant expertise to understand cultural constraints, challenges, and opportunities when planning research dissemination and hazard outreach and education initiatives.
Ensure improved and equitable access to hazard information	Enhance communication training for natural hazard scientists.	Pursue open-access publishing. Co-develop research outputs and dissemination.	Produce short, accessible summaries of hazard research (e.g. policy briefs) for stakeholders.
Champion people-centred DRR – leaving no one behind	Include training on integrating local and indigenous knowledge and perceptions into natural hazard assessments and disaster risk reduction.	Actively reflect on how underrepresented, vulnerable, and marginalised groups can meaningfully participate in and benefit from research.	Focus hazard education and outreach initiatives specifically on vulnerable and marginalised groups, including in schools.
Improve links between DRR and sustainable development	Include training in public policy, to facilitate greater connection of hazard science to sustainable development priorities.	Consider how individual projects join up and relate to regional, national, and local sustainable development; DRR; and disaster risk management strategies.	

achieve one of the recommendations in Sect. 2 (e.g. prioritising positive partnerships, Sect. 2.2) could also reinforce other changes (e.g. ensuring equitable access to appropriate information, Sect. 2.5). Although we set out seven distinct themes in Sect. 2, we recognise there are interactions and note the importance of thinking across these themes in an integrated manner. For example, a professional skills module in undergraduate or postgraduate courses that integrates communication, policy engagement, stakeholder mapping, and partner-

ship development training could help deliver many of the ambitions expressed in Table 3. This could also involve opportunities for students to engage with other disciplines engaged in DRR, to understand their approaches and data requirements.

The vision of change we present requires transformation to natural hazard science education and training, introducing new skills and exposing scientists to a wider range of disciplinary knowledge, along with the option to learn interdisciplinary and transdisciplinary research approaches. This in-

cludes recognising the role of local or indigenous knowledge, demonstrated to be key to community-level risk reduction (e.g. Šakić Trogrlić et al., 2019). As Donovan et al. (2011) notes sometimes stepping into the interdisciplinary space can be actively discouraged, but cultural and ethical understanding, cross-disciplinary communication, and social science research approaches can enhance natural hazard science if included in scientists' training (Lubchenco et al., 2015; Gill, 2017; Stewart and Gill, 2017).

Effective communication is a repeated theme in many of the recommendations in Sect. 2, across sectors, disciplines, and cultures. Yet much of the existing communication training offered to university students focuses on communicating natural hazard science to fellow natural hazard scientists or the public who reside in the same national context as the place they are a student. In contrast, it could be enriching to bring students together from geoscience, engineering, anthropology, health sciences, geography, and the political sciences to explore their research tools, information requirements, and preferred ways of giving and receiving information. Cross-disciplinary engagement at an early stage of a career would likely result in a strengthened understanding of ethics and appreciation of interdisciplinary partnerships throughout their work.

Reforms to the training of natural hazard scientists should be complemented by the adoption of different approaches to determining research questions, building research partnerships, and connecting research to decision makers. Effective partnerships, with clear roles and responsibilities, are important (Sargeant et al., 2018), and these will increasingly include a wider variety of skills and disciplines (e.g. ethnographers, behavioural scientists). Equitable and ethical partnerships take time to develop and maintain, but this should not be an excuse for poor partnership practice. Natural hazard scientists in the Global North have a professional responsibility to listen to the needs and priorities of natural hazard scientists and stakeholders in Global South nations and work with them to address these. Working in partnership, and listening to stakeholders, is fundamental to understanding critical aspects of local context, ensuring effective communication, and including marginalised groups. This process of listening is not a one-off exercise, but iterative and requiring continual engagement.

Whilst individual behaviours can promote change, we recognise that there are a number of institutional and financial transformations required, including improving funding mechanisms to include non-academic partners in research proposals, supporting the development of new training schemes and providing funding for open-access publishing.

4 Conclusions

This perspective paper has provided evidence and recommendations for how natural hazard scientists can contribute

to reducing disaster risk and securing the ambitions of the SDGs. Natural hazard scientists' understanding of Earth processes and dynamics underpins hazard analysis, which (alongside analysis of other disaster risk drivers) in turn informs the actions required to manage and reduce disaster risk. This paper recommends actions the natural hazard science community can take to enhance the contribution of their work to the planning and development of sustainable and resilient communities. We recommend changes to (i) education, training, and continued professional development; (ii) research design, methods, and implementation; and (iii) institutional, financial, and policy actions, to strengthen the translation, adoption, and effective application of their understanding of physical processes and hazards to reduce disaster risk. In addressing the priorities for change set out in Sect. 2, and summarised in Table 3, we propose the following benefits.

- *Richer data and better understanding of the physical multi-hazard landscape.* Improved integration of data characterising different natural hazards, from a wider range of sources (e.g. integrating indigenous knowledge), will enable a richer understanding of the multi-hazard landscape and potential complex and compound hazard scenarios.
- *Improved capacity building.* Natural hazard scientists will grow in their awareness of capacity (of individuals and organisations) and their ability to develop the capacity of others through locally and culturally appropriate means.
- *Better partnerships.* Natural hazard scientists will work in a more ethical manner, with greater sensitivity to context to support (vs. undermine) other partners. Natural hazard scientists will have a clearer understanding of how to engage with vulnerable communities, increase their access to information, and actively reflect on whether and how they are able to participate in DRR activities.
- *Increased access and use of natural hazard science.* Listening to stakeholders' questions, understanding their decision-making processes, and building cultural understanding can inform the natural hazard science that is done and the way this is shared with others to encourage the embedding of science within policy and practice.
- *Improved identification and mitigation of unintended negative consequences.* Through the adoption of approaches such as “Theory of Change”, understanding of cultural context, and engagement with a broader pool of expertise and relevant stakeholders, it should be easier to identify potential negative consequences of particular research activities or knowledge exchange activities resulting from these activities. Steps can then be taken to avoid or mitigate these negative consequences.

Together these benefits will support DRR, and the development of sustainable and resilient communities. It is now the responsibility of individual natural hazard scientists and those in positions of leadership (e.g. course directors, funding agencies) to consider how the recommendations set out here apply to their work and what more they can do to ensure natural hazard science helps realise the ambitions of the Sendai Framework and UN Sustainable Development Goals.

Code and data availability. Literature used to inform this invited perspective is set out in the reference list.

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