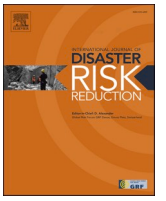
International Journal of Disaster Risk Reduction 115 (2024) 105041

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr



Communicational responses for compound natural hazards: A systematic review

Noelle Nemeth [a,d], Malcolm S. Johnson [a,c,d], Gabi Mocatta [b,c,d,*], Erin Hawley [a,d]

[a] School of Communication and Creative Arts, Deakin University, 221 Burwood Hwy, Burwood, VIC, 3125, Australia
[b] Climate Futures, University of Tasmania, Sandy Bay Campus, Private Bag 50, Hobart, TAS, 7001, Australia
[c] School of Geography, Planning and Spatial Sciences, University of Tasmania, Sandy Bay Campus, Private Bag 50, Hobart, TAS, 7001, Australia
[d] Natural Hazards Research Australia, PO Box 116, Carlton South, VIC, 3053, Australia

ARTICLE INFO

Keywords:
Compound natural hazards
Multi-hazard
Hazard communication
Systematic review

ABSTRACT

Compound natural hazards are being experienced globally and are expected to become more frequent and damaging under climate change. Communities at risk from compound hazards must be well-equipped with knowledge about such hazards and recognise what actions are needed to prepare, stay safe and recover. Despite this imperative for awareness, education, communication and engagement on compound hazards, there is little discrete research on their best-practice communication. This paper utilises the systematic quantitative literature review process to identify and analyse global literature addressing communicational responses to compound hazards. The review highlights that the term 'compound hazards' is not agreed upon in the literature, and that several analogous terms are used. Review findings also establish that no existing frameworks or protocols for compound hazard engagement or communication exist in the English language literature. This suggests that more research is needed to support those charged with hazard management in communicating compound hazard risk with the communities they serve. Ultimately, we recommend further research on the development of communication frameworks for compound hazards.

1. Introduction

Natural hazards threaten lives, property and ecosystems in diverse locations, globally. The frequency of extreme weather events has increased since the 1970s [1] with hazard incidence projected to rise in the future under climate change [2]. In this context of hazard escalation, hazards are no longer always discrete events. Instead, hazards can coincide spatially or temporally, compounding the effects of each. In Australia, for example, a country that has experienced multiple recent disasters, the National Disaster Risk Reduction Framework refers to a "growing potential for cumulative or concurrent, large-scale natural hazards to occur" [3]. As climate change and population growth increase the risk of such 'compound hazard' events, it is essential to identify how emergency managers might engage more effectively with the communities they serve to promote awareness and preparedness, survival and recovery, in the face of compound natural hazards [4].

Research to date has established that clear and purposeful communication can act effectively to reduce risk in hazard environments

* Corresponding author. Climate Futures, University of Tasmania, Sandy Bay Campus, Private Bag 50, Hobart, TAS, 7001, Australia.
E-mail addresses: noelle.nemeth@deakin.edu.au (N. Nemeth), malcolm.johnson@utas.edu.au (M.S. Johnson), gabi.mocatta@utas.edu.au (G. Mocatta), erin.hawley@deakin.edu.au (E. Hawley).

https://doi.org/10.1016/j.ijdrr.2024.105041
Received 31 July 2024; Received in revised form 29 November 2024; Accepted 1 December 2024
Available online 2 December 2024

[5]. Conversely, poor access to communication infrastructures and inadequate communication practices in relation to hazards can increase people's vulnerability to disasters [6]. Education, communication and awareness-raising on disaster risk are central to the provisions of the Sendai Framework on Disaster Risk Reduction, which calls for a strengthening of "public education and awareness in disaster risk reduction, including disaster risk information and knowledge, through campaigns, social media and community mobilization, taking into account specific audiences and their needs" [7]. As a research team based in Australia, we note that Australia's National Disaster Risk Reduction Framework similarly considers it a "priority 1 action" to "improve public awareness of, and engagement on, disaster risks and impacts" [3]. Given the need for better communication in the disaster risk reduction space, there is growing recognition in the literature that strategies relying on deficit model, top-down forms of communication are less helpful for engendering protective behaviours. Conversely, strategies that are more focused on reciprocal communication with communities have been shown to better support preparedness, response and recovery [8–10].

Despite the current imperative to more effectively engage with communities in relation to risk from hazards, and the need to prepare for compound hazards specifically, best-practice guidelines for compound hazard communication, education and engagement have not yet been established. In jurisdictions like Australia, where guidelines for hazard communication and community engagement do exist, they generally make little or no mention of compound hazards [11]. Likewise, even recent and detailed examples of scholarly literature on awareness-raising for natural hazard preparedness do not mention compound hazards or analogous concepts [12,13]. Conversely, in existing reports [14] and frameworks [15] related to compound hazards specifically, communication, education or awareness raising are not mentioned. This leaves a gap in current knowledge about how emergency management agencies and other governance bodies charged with responding to hazard events should communicate and engage with communities to raise preparedness for and resilience to compound natural hazards.

Even more fundamentally, there is no consensus in the research literature, and in current usage, about what exactly constitutes a 'compound natural hazard'. The use of the term 'compound hazard' itself is not well established as a widely accepted descriptor for events in which hazards co-occur, interact, or in which they follow each other within a short time period [16,17]. In the global literature reviewed, this paper finds several different terms being used interchangeably to describe or approximate the concept of compound hazards [18–20]. Crucially, the way these terms are used is not agreed on, and sometimes alternative terms are used ambiguously, making the definition of compound hazards even more complex.

The objective of this paper is to undertake a systematic quantitative literature review (SQLR) to assess the existing global literature on communication, education, public engagement, and awareness-raising efforts for compound natural hazards. SQLRs are framework-based or theme-based reviews that rely on an established methodology to steer research through a structured process of extracting important insights, identifying knowledge gaps, and providing directions for future research [21]. In this paper, in recognition of the noted ambiguity of definition of compound hazards, we first clarify the multiple different descriptors identified in the literature as analogous with the term 'compound hazard'. We illustrate this with a visual that defines compound natural hazards, clearly breaking down the elements comprising the concept. Following this, we summarise the systematic review's results, documenting strategies for raising publics' awareness of, and preparedness for compound natural hazards. We also seek to establish which actors are engaged in carrying out such activities. We conceptualise communication, education, engagement, and awareness-raising, broadly, as *communicational responses* to compound hazards. Ultimately, the spectrum of such existing communicational responses must be closely appraised in order to define best-practice compound hazard communication. This is a necessary step towards informing emergency managers on how best to operationalise communicational activities and responses in the context of proliferating compound hazard risk.

The SQLR process highlights key themes, concepts and absences to ultimately inform and assist both academic research direction and risk governance, decision making and operational practices. The findings of an SQLR present a baseline dataset and establishe gaps in the literature, on which future academic research can build. This paper seeks to answer the following research questions:

- What terms are used in existing literature to define 'compound natural hazards'?
- What constitutes a 'compound natural hazard?'
- What strategies are identified in the global literature for raising publics' awareness of, and preparedness for compound natural hazards?
- Who communicates on compound natural hazards?

2. Background

2.1. Defining compound natural hazards

Globally, many geographic locations are subject to *compound natural hazards:* disasters or events with overlapping spatial and temporal attributes [22]. The diverse terminology used to describe the phenomenon of multiple, often linked, or interdependent hazards includes multi- or multiple-hazards, hazard cascades; as well as cascading, chain, sequential, co-occurring, concurrent, overlapping, combined, simultaneous, and aggregate hazards. *Compound hazards* have also been described as coupled events or follow-on events, which have cross-hazard effects, domino effects, synergic effects, triggering effects or knock-on effects as well as interactions and interrelations [23,24].

Compound events, specifically, have been defined as: "two or more extreme disaster events occurring simultaneously or sequentially, combinations of extreme events with underlying conditions that amplify their impact, or combinations of events that are not themselves extreme, but which collectively result in an extreme aggregation of impacts" [25]. They can also be defined as "comprising more

than one disaster event, occurring contemporaneously or within a short timeframe" [22]. *Compound events* are also described as events that are correlated in space and/or time but result from distinct causal pathways. As hazard interactions are highly variable in terms of space and time, and can operate on various scales, *compound hazards* are conceptually difficult to delineate [24]. *Multiple hazards* are considered events that coincide and occur in the same region within a particular period, regardless of whether the events are linked or not [26]. They can also be defined as hazards "following one another with damaging force – for instance, floods during a drought, or hurricanes followed by landslides and floods" [23].

Other terms, such as *cascading disasters* or *disaster chains*, refer to hazards that trigger a second event and are influenced by each other but do not occur concurrently [27]. They are defined as "extreme events, in which cascading effects increase in progression over time and generate unexpected secondary events of strong impact" [28], and when "a sequence of physical, social, or economic disruptions occurs over time and generate secondary events of strong impact" [22]. An often-cited cascading disaster is Japan's 2011 Tohoku earthquake, where a magnitude 9.0 earthquake triggered a tsunami, which, in turn, led to a nuclear disaster. This event ultimately killed 15,883 people [28]. An additional *multiple hazard* type is so-called *Natech hazards,* in which a natural hazard triggers a technological accident or disaster event [24], such as floods leading to toxic chemical spills.

The following definition of *multiple hazards* likely encompasses all possible combinations of hazard types discussed above: "(1) the selection of multiple major hazards that the country faces, and (2) the specific contexts where hazardous events may occur simultaneously, cascadingly, or cumulatively over time, and taking into account the potential interrelated effects" [17]. Overall, of note in the literature is that many disparate terms are used to describe multiple hazards occurring in the same place, and that inconsistencies between scopes and definitions remain, with the same term defined inconsistently or various terms being used interchangeably [29]. There are also disagreements in the literature as to exactly which events constitute compound events (e.g., 'natural disasters', technological events, pandemics) and within what spatial or temporal range such events must occur to be considered 'compound'.

It is worth noting, in addition, that terminology around disasters is disputed in the literature more broadly. Although the terms 'natural disasters' and 'natural hazards' are often used interchangeably in research and also in everyday parlance, these terms do not necessarily equate. While in many cases, hazards are no longer purely "natural" as a result of anthropogenic climate change, even '"unnatural" hazards only become disasters when they interact with existing exposures and vulnerabilities [30]. Such exposures and vulnerabilities are often the result of socio-political processes: that is, they are human-induced. It has been argued therefore, that the term 'natural disasters' is erroneous, and has the implication of absolving human behaviour from any responsibility for such events, when commonly, 'natural' and human factors are intertwined [31]. In this paper we have avoided the term 'natural disaster' for this reason.

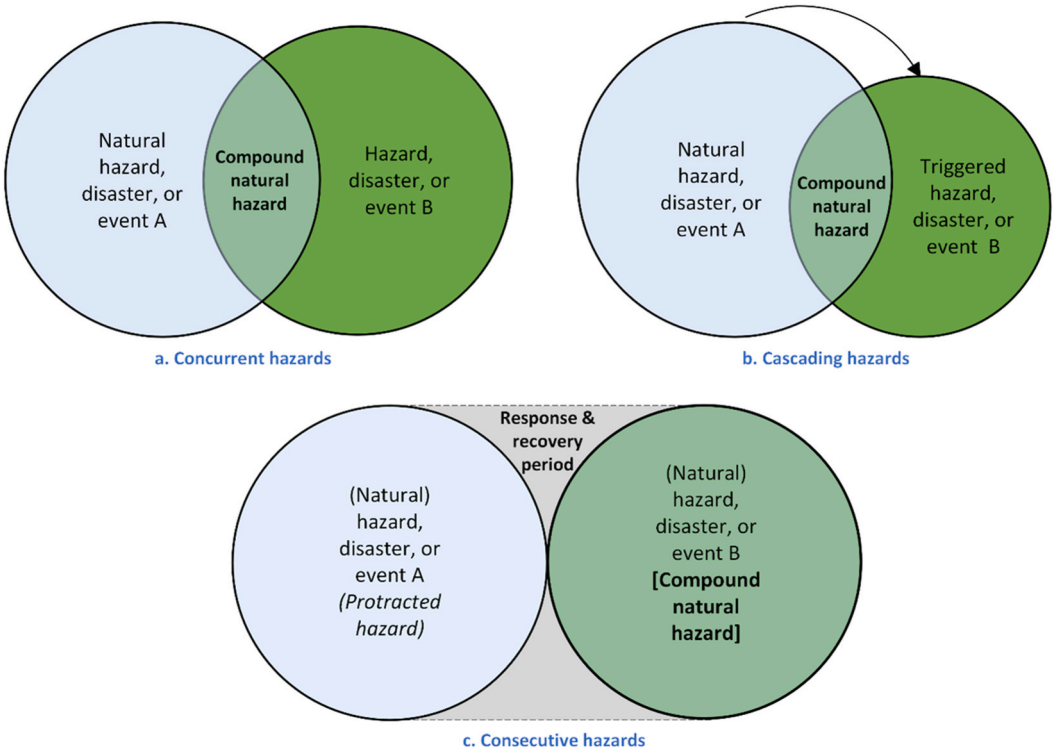


Fig. 1. Types of compound natural hazard connections including a. Concurrent hazards, where at least two hazards (one of which being a natural hazard) occur at the same time or in the same space; b. Cascading hazards, where an initial natural hazard triggers or causes subsequent hazards, natural or otherwise; and c. Consecutive hazards, where during the response or recovery period of a natural hazard that has "ended", an additional hazard occurs, natural or otherwise.

2.2. Spatiotemporal hazard scales

Building on the multiple, interconnected definitions and overlapping terminology for compound natural hazards established above, we have determined several key features that consolidate the often-disparate literature within our definition of compound natural hazards. The resulting body of literature was subsequently assessed in this systematic quantitative literature review. Beyond the terminology used or the types of hazards present, compound natural hazards are described in terms of the spatiotemporal overlap of events [26].

Temporally, compound hazards can either occur *simultaneously* (with at least two hazards arising around the same time) or *subsequently* (whereby a second hazard happens sometime after the initial hazard, either as a triggered event or discrete hazard) [32,33]. A major challenge in defining temporality is identifying the "end" of a disaster or hazard event when there is often no established timeframe, starting point, or end period. The temporal duration of compound hazards can vary from days to months and, in some situations, even years, given response and recovery periods (e.g., it may take years to fully "recover" from the impact of a super typhoon) or if the hazard is no longer considered present or pertinent (e.g., such as in the second or third year of the COVID-19 pandemic) [34,35]. Spatially, compound hazards must overlap in the same geographical area; however, the scale of the hazards need not be equivalent. For example, a large region may be suffering from drought when a part of that region experiences a fire event. Delineating the spatial limits of what is defined as a compound hazard is often dictated by hazard management, planning, and/or policy systems. Therefore, there are likely more compound natural hazards occurring on a global scale than are presently reflected in the research literature [36].

2.3. Connections between hazards

Based on the spatiotemporal criteria outlined above, there are broadly three types of compound natural hazard connections (Fig. 1). *Concurrent hazards* are when at least two discrete hazards occur simultaneously, and where one hazard is naturally occurring (e.g., flood, fire, storm). *Cascading hazards* involve an initial natural hazard triggering or causing subsequent hazards that overlap in space and time. For example, when an earthquake triggers a tsunami [28] or when a heavy rainfall event triggers a landslide [37]. *Consecutive hazards* happen when an initial hazard has "ended" but a given location remains in a response or recovery period during which subsequent hazards occur, thus creating a compound hazard environment. Examples include multiple floods occurring within the space of several weeks or months [34] or an earthquake occurring at the tail end of the COVID-19 pandemic, considered a *protracted hazard* [38].

2.4. Elements of compound hazards

Based on the literature, there appear to be six key elements that contribute to the definition of compound natural hazards (Fig. 2). The following descriptions include a limited selection of examples that is expanded on as part of the review process:

1. The general terms used to describe two or more events (e.g., compound, cascading, multiple), which are often used interchangeably within a single paper.
2. The term used to describe the event (e.g., hazard, disaster, or event), which is typically associated with specific hazard/disaster/event types *or* with certain disciplines.
3. The type of hazard described (e.g., natural, human-made, or hybrid), noting that our definition excludes compounding human-made hazards.
4. The type of connection between disasters (e.g., concurrent, cascading, or consecutive), as described above.
5. The temporal scale of disasters or the timeframe between two hazards (e.g., days, months, or years), noting that determining the "end" of a hazard event is often difficult.
6. The spatial scale of the hazards or the extent of impacted locations (e.g., local, state, or national), which typically aligns with planning units (e.g., local government area, state borders).

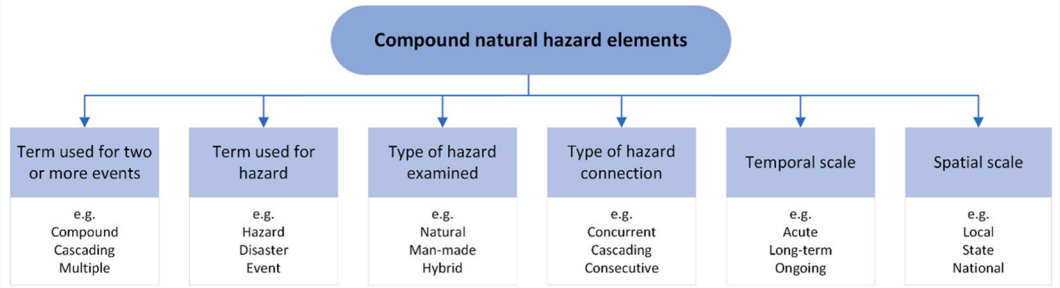


Fig. 2. Elements that constitute a compound natural hazard.

However, the identified elements of a compound natural hazard are not always recorded, discussed, or clarified in the literature, which highlights the complexity of the notion of *compound natural hazards* and the associated variety of terms and interpretations. Using the systematic quantitative literature review process, we assessed the literature, focusing on papers discussing compound natural hazards that include responses, recommendations, or information about communication, awareness, engagement, and/or education for such hazard events.

3. Communicational responses to compound natural hazards

In this paper, we use the SQLR process to baseline existing literature and then identify how *communicational responses* to hazards can best be operationalised to increase community preparedness, response, recovery and ultimately, resilience. Communicational responses include the wide spectrum of information dissemination before, during and after hazard events that catalyses communities' and individuals' preparedness for compound events, survival during events, and recovery post-event(s). Communicational responses to compound natural hazards encompass education, communication, awareness, and engagement initiatives, strategies, practices, interventions, and approaches that raise people's understanding of the potential for compound hazards to occur in a particular location and how they might be experienced differently from singular hazards. We use the terms 'strategies', 'initiatives', 'practices', 'interventions', and 'approaches' interchangeably throughout this paper and note that these can occur across spatiotemporal scales. In the sections below we provide further definitions for what we consider to be communicational responses.

3.1. Communication

Communication is defined in this paper as all the information dissemination that occurs in relation to hazards by any means or technology – from interpersonal to digitised – and at any stage in the occurrence of hazards, including in times when no hazards are occurring or forecast. In this definition, we acknowledge critiques of a one-way, deficit model of communication [39], though we recognise that this model is still commonly used operationally for disaster risk and resilience communication [9]. We also encompass in this definition multi-directional communication, including co-construction of communicational responses with at-risk communities, and *listening* to communities [40].

3.2. Education

Education in the context of compound natural hazards is typically defined around imparting information needed for preparedness. Education can include instruction in schools and universities, but also extends beyond the classroom to include information or training programs in community settings. Education may signify a one-way communicational endeavour – the imparting of knowledge by experts to non-experts. This often focuses on encouraging voluntary risk reduction activities, while also seeking to build public acceptance of any compulsory measures [41]. We define education as learning and knowledge transfer about natural hazards, which may take place in a formal education setting, or outside it. We encompass both one-way and multi-directional knowledge transfer, noting that emergency managers may also need to *learn from* the communities they serve.

3.3. Awareness

We define hazard awareness as the information and knowledge people have about the likelihood of a hazard occurring in a place, usually their own locality [42]. Awareness also includes the possible severity of a hazard and understanding of how to reduce vulnerability through preparedness [43]. Awareness is broadly achieved through educational and communicational initiatives. Trust in the communicator, and prior experience of hazards are noted as important factors in awareness-raising [42].

3.4. Engagement

We acknowledge the intersections between these terms, and that education, communication, and awareness-building are all types of *engagement*. We emphasise that engagement is an inherently communicational activity – there cannot be engagement without communication in some form. Engagement on compound hazards is therefore any of the above-mentioned activities in which communities, individuals and those tasked with managing hazards come together for knowledge transfer – which can be one-way (with the caveats to this approach noted) or multi-directional.

4. Methods

We use the systematic quantitative literature review (SQLR) process to assess the existing literature on the intersection of compound natural hazards and communicational responses. The purpose of an SQLR is to systematically assess for gaps in the global literature to determine key themes, concepts and absences to inform academic research direction and assist risk governance, decision making and operational practices [44,45]. SQLRs, like other framework-based reviews [21], are a research methodology with an organising framework and meticulous structure that produce and present findings in a robust and reproducible manner [44,45]. We follow the SQLR framework to systematically map and present findings across specific issues, methods, locations, and questions.

Our review search was completed between end-September 2023 and early October 2023 with reference to the PRISMA 2009

guidelines [46]. SQLRs are a snapshot in time, presenting a baseline dataset on which future academic research can build [44,45]. We searched Scopus and Google Scholar databases using combinations of predetermined keywords involving three key components: (i) the compound or cascading factor, (ii) the natural hazard factor, and (iii) relevance to education, communication, awareness, or engagement. Relevant articles were systematically identified for inclusion by undertaking searches in the selected scholarly databases using targeted keywords and Boolean search functions ("AND" and "OR"). Results were screened for inclusion or exclusion based on the title, abstract, and content by the authors to ensure consistency given the complex nature of the topic. Duplicates were removed.

The full text of remaining articles was further assessed by at least two of this study's authors for relevance. The research team also assisted in the screening process to address any questions and provide input on the final inclusion of articles. Any full-text articles that did not explicitly refer to *compound* hazards, were only literature reviews, or provided no information on education, communication, awareness, or engagement strategies were excluded. This process identified 45 articles for final inclusion, as illustrated in Fig. 3.

4.1. Compound natural hazards and analogous terms

Various terms and definitions are used to refer to compound natural hazard events. Hazards are described as "natural," "weather," "climate," or "extreme" and can also be denoted "disasters" or "events." To refer to multiple hazards occurring simultaneously, there are several synonyms which were identified to use in the search strategy for the SQLR. These included 'compound', 'cascading' 'multiple', 'multi-hazard', 'simultaneous', 'co-occurring', 'combined', 'concurrent', 'overlapping', 'sequential' and 'consecutive'. This is not an exhaustive list, as the SQLR results show: numerous other synonyms are used to refer to compound or cascading disasters.

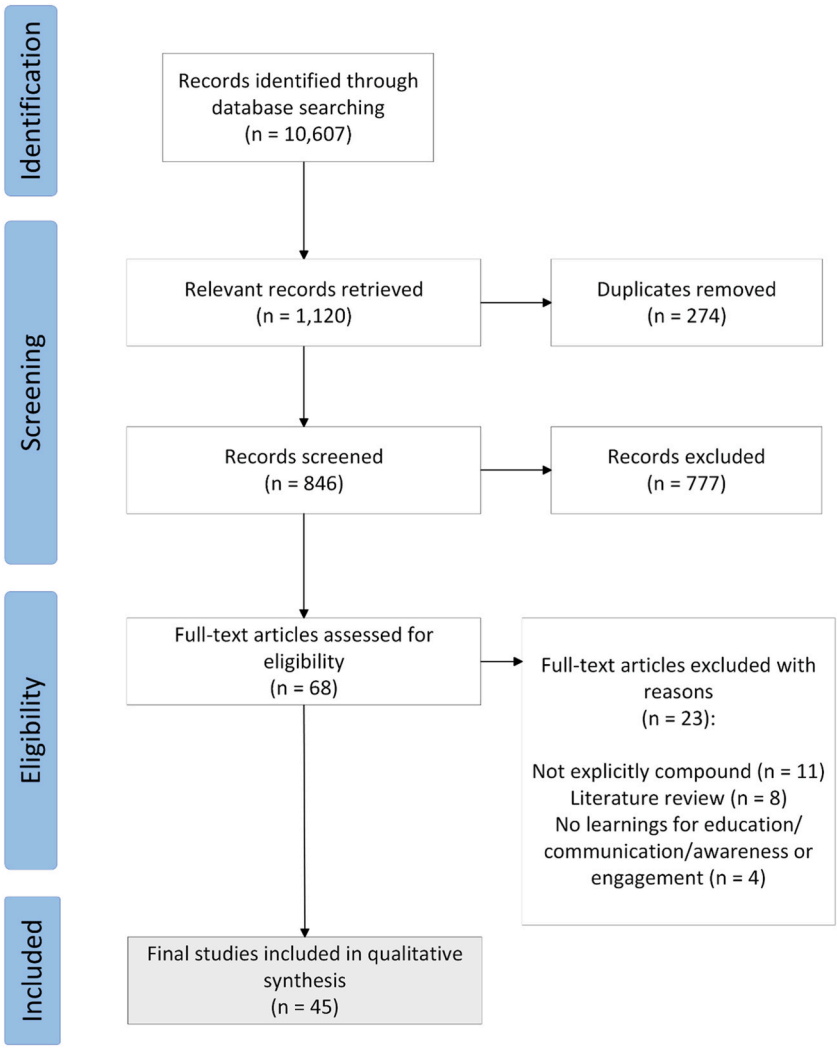


Fig. 3. PRISMA diagram of article screening process.

4.2. Search strategy

The search strategy included multiple search approaches, including direct (e.g., searching exclusively using the key concepts), consecutive (e.g., searching for a series of similar concepts and combing results), and reflexive (e.g., conducting additional searches after identifying new concepts). During a preliminary search, the term 'framework*' was included but did not generate includable results. Similarly, the term 'engage*' was not initially used in the search but was added later based on literature results and conversations between the research team. Search strings were searched again following these changes and any papers that were flagged for inclusion were reassessed for their presence in the new set of results.

Peer-reviewed literature databases were used to search and identify relevant studies. The key databases utilised were Scopus and Google Scholar, as summarised in Table 1 below. The database fields searched included titles, abstracts, and keywords. The search targeted research published between 2014 and 2023, to make the review recent, relevant, and manageable within the study time frame. The Scopus combined search term was entered in one search (no restrictions on character limit), and all results were assessed.

To search the Google Scholar database, each search combination term (except for multi-hazard) was searched for the first 20 results due to the large variation of search terms used in this field. As Google Scholar has a 256-character limitation, each variation of the first term was searched individually with the associated "AND" strings to ensure all relevant results were displayed. The "multi-hazard" search term was searched beyond the first two pages due to the prevalence of the term (over 7000 results alone can be attributed to it). Results were scanned by two team members page by page to determine the extent of the search, and ultimately, the first 150 results were included. Beyond page 15, results appeared largely irrelevant.

4.3. Inclusion and exclusion criteria

After removing duplicates from the combined search results (n = 274), the remaining papers were screened on exclusion and inclusion criteria. Throughout the screening process and full-text assessments, articles were excluded if they did not meet the eligibility criteria. Most articles (n = 777) were excluded during the initial screening process. Articles focusing on compound natural hazard events or cascading events where the second disaster was human-caused (e.g., COVID) were also included. Of the remaining papers retained for full-text assessment (n = 68), several (n = 23) did not meet the inclusion criteria upon closer inspection (i.e., papers were initially screened and included but then excluded after a detailed assessment).

Table 1
Search terms used and the total number of articles identified.

Database	Terms Searched[a]	Articles Identified
Scopus	("natural hazard" OR "natural disaster" OR "natural hazard event" OR "natural event" OR "weather event" OR "climate event" OR "extreme event") AND ("compound hazard" OR "multi-hazard" OR "multiple hazard" OR "combined hazard" OR "co-occurring hazard" OR "cascading hazard" OR "concurrent hazard" OR "simultaneous hazard" OR "overlapping hazard" OR "compound natural hazard" OR "multi-natural hazard" OR "multiple natural hazard" OR "combined natural hazard" OR "co-occurring natural hazard" OR "cascading natural hazard" OR "concurrent natural hazard" OR "simultaneous natural hazard" OR "overlapping natural hazard" OR "compound disaster " OR "multi- disaster " OR "multiple disaster " OR "combined disaster " OR "co-occurring disaster " OR "cascading disaster " OR "concurrent disaster" OR "simultaneous disaster" OR "overlapping disaster" OR "compound event " OR "multi-event " OR "multiple event " OR "combined event " OR "co-occurring event " OR "cascading event " OR "concurrent event" OR "simultaneous event" OR "overlapping event") AND (educat* OR aware* OR communicat* OR engage*)	365
Google Scholar	"compound hazard", "multi-hazard", "multiple hazard", "combined hazard", "co-occurring hazard", "cascading hazard", "concurrent hazard", "simultaneous hazard", "overlapping hazard" Google Scholar option 2 AND ("natural hazard" OR "natural disaster" OR "natural event" OR "weather event" OR "climate event" OR "extreme event") AND (educat* OR aware* OR communicat* OR engage*)	8020
	"compound disaster", "multi-disaster", "multiple disaster", "combined disaster", "co-occurring disaster", "cascading disaster", "concurrent disaster", "simultaneous disaster", "overlapping disaster" AND ("natural hazard" OR "natural disaster" OR "natural event" OR "weather event" OR "climate event" OR "extreme event") AND (educat* OR aware* OR communicat* OR engage*)	1488
	"compound event", "multi-event", "multiple event", "combined event", "co-occurring event", "cascading event", "concurrent event", "simultaneous event", "overlapping event" AND ("natural hazard" OR "natural disaster" OR "natural event" OR "weather event" OR "climate event" OR "extreme event") AND (educat* OR aware* OR communicat* OR engage*)	734
Total articles identified		**10,607**

[a] "Sequential" was trialled as a search term but did not yield any relevant results and, therefore, was not included as a key search term.

Studies were included if they met all the following criteria:

- Focused on compound or cascading natural disasters per the definitions outlined in the background section. This focus needed to be the main premise of the study.
- Identified strategies for education, awareness, communication, or engagement beyond simple mentions.
- Provided detailed descriptions of how education, communication, awareness, or engagement in the context of compound natural hazards could be useful for future planning.
- Written in English or available as an English translation.
- Accessible through open access or institutional access.

Articles were excluded during screening if they were literature reviews, targeted only anthropogenic hazards or hazards that did not geographically overlap, focused exclusively on infrastructure or engineering, education institutions, Disaster Risk Reduction (DRR), the Sendai Framework, or resilience frameworks without any learnings for education, awareness, communication, or engagement. Other reasons for exclusion included papers that were not explicitly on compound hazards or only mentioned education, communication, awareness, or engagement in passing without providing any practical application for these communicational responses to compound natural hazards. With the “multi-hazard" search term, many results focused on assessing multiple types of hazards individually; however, they did not address or focus on multiple hazards occurring simultaneously. In this case, they were excluded unless they discussed the occurrence of compound natural disasters.

While it is common for SQLRs to exclude grey literature outright, we have opted to include peer-reviewed book chapters (n = 9), doctoral dissertation/thesis chapters (n = 3), journal-published conference papers (n = 2), pre-prints of journal articles (n = 2), and reports (n = 1). Any studies that fell within these categories that were explicitly or exclusively literature reviews or duplicate publications from the same study (e.g., thesis chapters also published in peer-reviewed journals) were excluded. The decision to retain this research was to ensure the broadest understanding of the literature on communicational responses to compound natural hazards.

4.4. Data extraction and synthesis

In the final review, 45 articles were included in the database for qualitative data synthesis. To analyse the data, a comprehensive database was developed with key criteria that expanded over time with the uses of presence/absence identification (i.e., 1 = criteria present, 0 = criteria not present) in addition to text descriptors to provide supplemental information for the analysis phase. Publications were assessed using multiple methods (e.g., reading the paper and marking down presence/absence of criteria; using the ‘find’ command to target criteria; contextual reading around major terms).

The structure of the database includes several broad components: (1) general characteristics of the studies – article details, authors, keywords, year of publication, journal discipline, country of study, and methods used; (2) characteristics associated with the compound natural hazards – the type of disaster, combined hazard terms used, and hazard scale (temporal and spatial); and (3) details on the form of communication strategy or communicational response – tools defined, discussed or demonstrated and highlighted themes

Fig. 4. Author described keywords across all included studies. One paper had 27 keywords; six studies did not include any keywords.

across education, communication, awareness, and engagement. In addition to these three main categories, papers were assessed for mentioning climate change, which is considered a major contributing factor to the future intensity of compound hazards [47], and climate change responses (e.g., mitigation or adaptation), which interact with the hazards and interventions in nuanced ways. Papers were also assessed for referencing frameworks, as identified as a potentially critical facet of the literature. The complete database was then analysed for results using a combination of functions and visualizations of major database components and criteria.

5. SQLR results

The SQLR process resulted in 45 studies that were included in the qualitative synthesis, as summarised in Fig. 3. Throughout the results, we emphasise studies that have explicitly used the term "compound" in describing *compound natural hazards*, as distinct from studies that describe compound scenarios but opt for terms like *multi-hazard* or *cascading hazard*. In cases where totals equal more than the total number of studies (i.e., 45), studies have mentioned multiple terms as described in each section. See Supplemental Material A for the full database.

5.1. Study characteristics

5.1.1. Discipline and keywords

The journal or publication self-described disciplines varied across eight different areas, including Disaster Risk Reduction (14 studies), Science and Environment (12), Infrastructure and Built Environment (4), Management and Governance (4), Geography (4), Sustainability (3), Communication (2) and Development Studies (2), demonstrating diverse disciplinary concern with the topic.

The most frequently used keywords were risk (22), communication (11), multi-hazard (10), disaster (10), COVID-19 (8), hazard (8), and management (8), which were often used in combination with each other and other terms (e.g., "risk communication", "emergency management", "multi-hazard resilience"), indicating the wide use of the terms "risk" and "multi-hazard" in compound hazard contexts (Fig. 4). Variants on the term "compound" were rarely selected as keywords (4).

5.1.2. Total studies per year

Over the last decade, the number of papers published has increased substantially (Fig. 5), showing a trend increasing year-on-year, with 15 papers published in 2022 compared to only two papers in 2014. The use of the term "compound" is also seeing a recent surge, with more than 50% of papers since 2021 using the word. Future publications will potentially follow this trend given the marked increase in the number of papers using the term "compound" to describe hazards in this review.

5.1.3. Geographic locations of hazards researched

A total of 50 countries were discussed or described in the studies with the United States (11 studies), Japan (8), Australia (6), the Philippines (6), and Indonesia (6) being most mentioned across studies (Fig. 6). Most studies (53.3 %) focused on a single country while one study discussed planning for compound natural hazards without mentioning a country (i.e., Bodin et al., 2022). There is a lack of studies focused on the Global South, which is especially stark given Global South countries' vulnerability to current and future compound natural hazards [47].

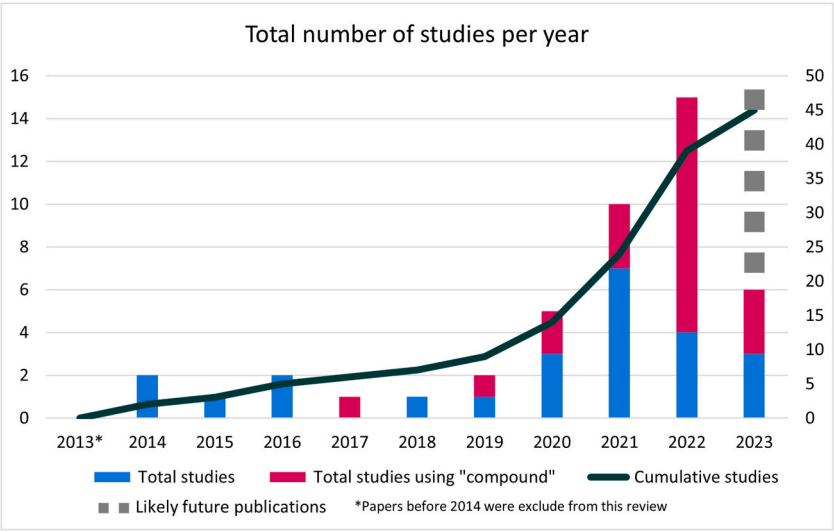


Fig. 5. Number of studies published by year with emphasis on studies using the term "compound".

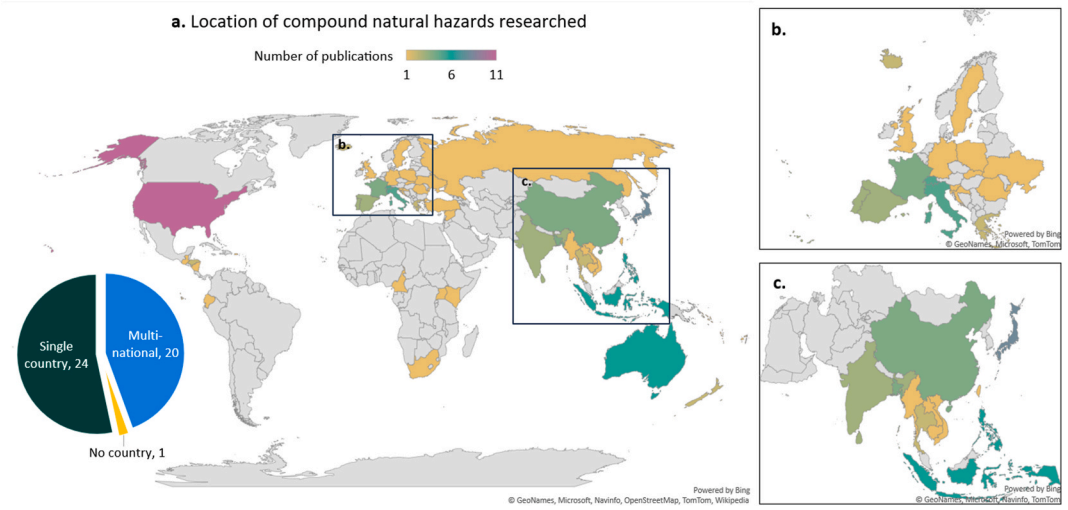


Fig. 6. Geographic locations examined by compound hazard studies.

5.1.4. *Study methods*

Approximately half of the studies (51 %) used mixed methods, while only five (11 %) used exclusively quantitative data. Out of twelve described methods (e.g., observations, field research, content analysis), the most common methods were case studies (19 studies), surveys (11), interviews (11), focus groups (7), and document analysis (6), with all other methods being used five or fewer times across all studies. Fifteen studies (33 %) described using two or more methods within a single study; however, in most instances, this was associated with detailing multiple case study methods within the publication [48]. There was no apparent link between method type or multi-methods and self-described "compound" studies.

5.1.5. *Climate change and mitigation/adaptation*

Due to the connection between climate change and compound natural hazards [47], studies were assessed for mentioning climate

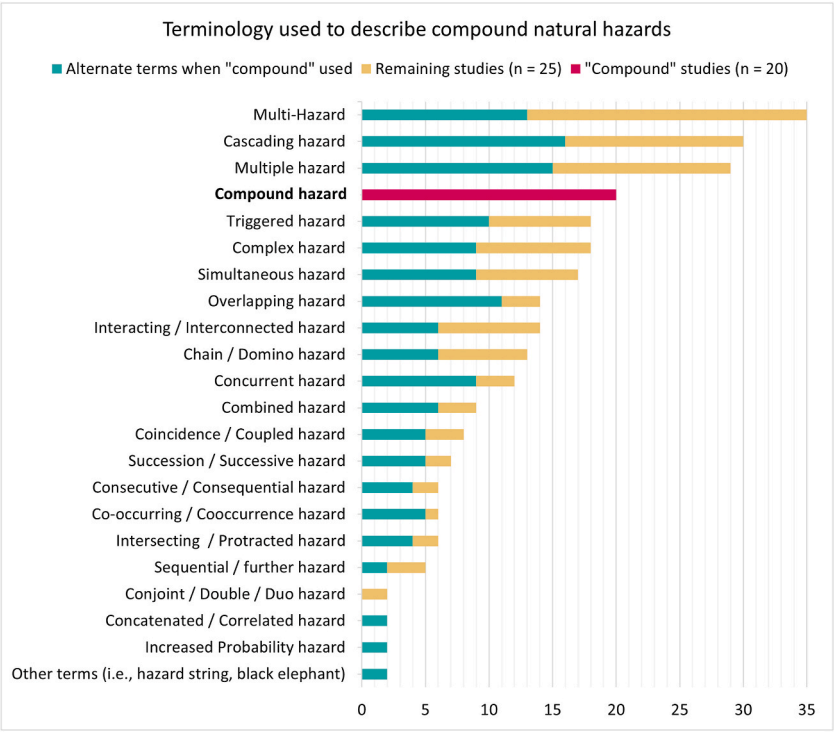


Fig. 7. Frequency of compound hazard terminology.

change and linking climate change with compound hazards. Only 26 studies (58 %) mentioned climate change in any capacity, with most (25 studies) noting it would have some effect on future hazards. However, only half of the studies referring to climate change (or 29 % of all studies) explicitly linked it to the compound natural hazards discussed in the study. While only a set of papers mentioned climate change, most studies (80 %) mentioned some form of prior adaptation or mitigation measures taken in response to the compound hazards discussed, with only nine studies not mentioning any prior actions. Of that subset, a combination of both mitigation and adaptation measures was most frequently mentioned (23), followed by mitigation only (11), and adaptation measures only (2).

5.1.6. Frameworks

Although many different types of frameworks are referred to within the papers, there are no mentions of existing communication/engagement/education frameworks specifically for compound natural hazards. The most referenced "framework" was the Sendai Framework for Disaster Risk Reduction (18 mentions), which seeks to prevent, reduce, and manage risk through integrated and multi-sectoral coordination [7]. While aligned with the focus of this study, compound natural hazards are not explicitly described in the Sendai Framework (i.e., "compounding" factors are described as non-hazard based, like demographic changes; however, a "multi--hazard approach" is a core feature of the framework). In addition to the Sendai Framework, studies mentioned approximately 16 distinct previously established frameworks, with eight studies presenting a "new conceptual framework".

5.2. Compound hazard characteristics

5.2.1. Compound hazard terminology

In addition to the term "compound", 22 other terms or phrases were used to describe compound natural hazards (Fig. 7). The most used terms were "multi-hazard" (35 mentions), "cascading" (30), and "multiple hazards" (29) with "compound" being used across 20 studies. Studies that described the hazards as "compound" typically used the term in conjunction with "cascading," "multiple," "multi-, "and "overlapping". Approximately half of all studies (49 %) used 5 or more terms within the same paper to describe compound hazards, with two papers using 15 different terms and one paper using only the term "compound" [49]. In many cases, studies defined compound hazards using a collection of terminology. For example, when Gill et al. [50] defined hazard types, they associated "compound" with "coincident" which they described as distinct from "concurrent or consecutive" while further associating the latter with "triggering interactions" and "increased probability interactions", all of which fall under our definition of "compound natural hazards".

5.2.2. Hazards studied in a compound hazard context

Less than half (47 %) of the studies provided a discrete definition for either "hazard" or "compound hazard", while typically papers demonstrated the compound nature of the hazards by listing the interactions between specific hazard types. Approximately 17 different hazard types were detailed across the studies, within which we determined that several hazard types were synonymous (e.g., hurricanes, cyclones, and typhoons) or were broad enough to be categorized (e.g., air/water pollution or health-related hazards). The most common hazard types described were floods (34 mentions), tropical cyclones (28), earthquakes (28), and fires (22), as well as an outsized number of mentions of COVID-19 (Fig. 8).

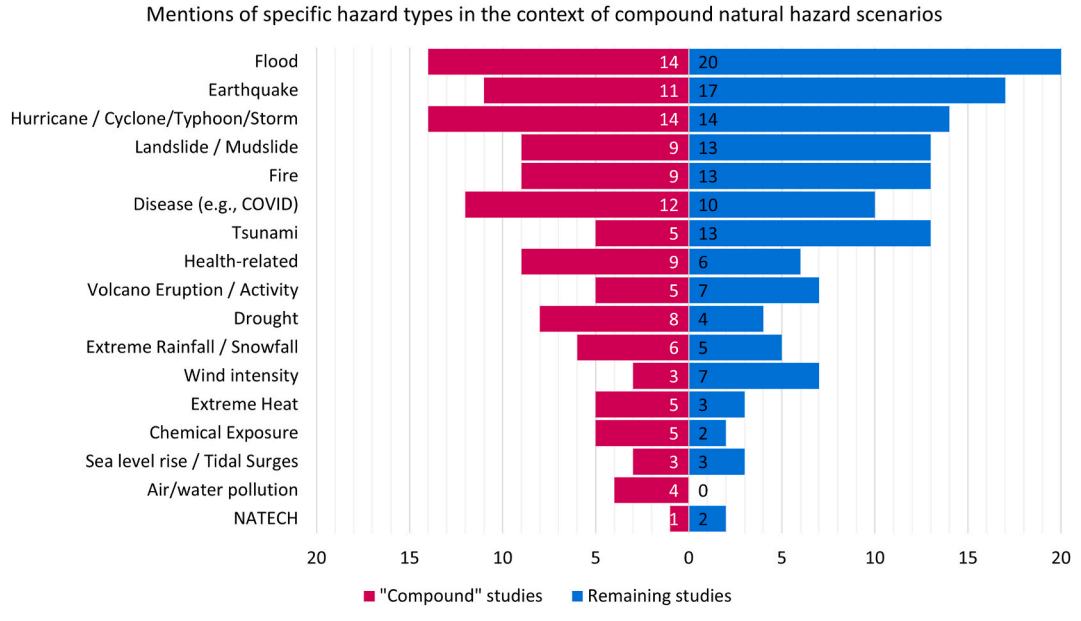


Fig. 8. Specific hazards studied in a compound context.

5.2.3. Compound hazard spatiotemporal scales

Less than one-third (29 %) of studies expressly defined the spatiotemporal scale at which the compound hazards in question took place: we determined these scales contextually. Most papers (62 %) investigated hazards across multiple spatial scales, ranging from structural (6 mentions), organisation/agency (4), local/community (33), state (22), national (24), and transnational (7). With regard to temporal scales, most papers (58 %) investigated only a single timeframe between either *acute* (27), meaning a compound event that took place over a relatively short period of time, or *long-term* (37), denoting a compound hazard where at least one hazard had been present for an extended period of time or were discussing the compound effects of multiple hazards over several years.

5.2.4. Communicational responses for compound hazards

Communication (42 mentions) was the most frequently mentioned response type for compound hazards, followed by awareness (39), education (29), and engagement (18), as determined by discussion (e.g., mentions) in text (Fig. 9). Precise definitions were rarely provided for any of these communicational responses (6–26 % by category). Instances where communicational responses were *demonstrated* (as opposed to just discussed) were similarly infrequent (22–57 % by category). It would be difficult to replicate any communicational responses that were not demonstrated because of their lack of explanation and detail. Subcategories and timeframes for communicational responses to hazards are described in the subsequent sections.

5.2.5. Education

Education strategies for compound hazards usually occurred before hazards (97 %). The most frequently discussed activities out of the 29 studies mentioning education were disaster preparedness education (14 studies mentioned these), workshops/seminars/trainings (12), risk reduction programs (10), and community-based education (9). The most frequently mentioned institutions implementing the education activities were dedicated education programs (15) and governments (12). School-based and university

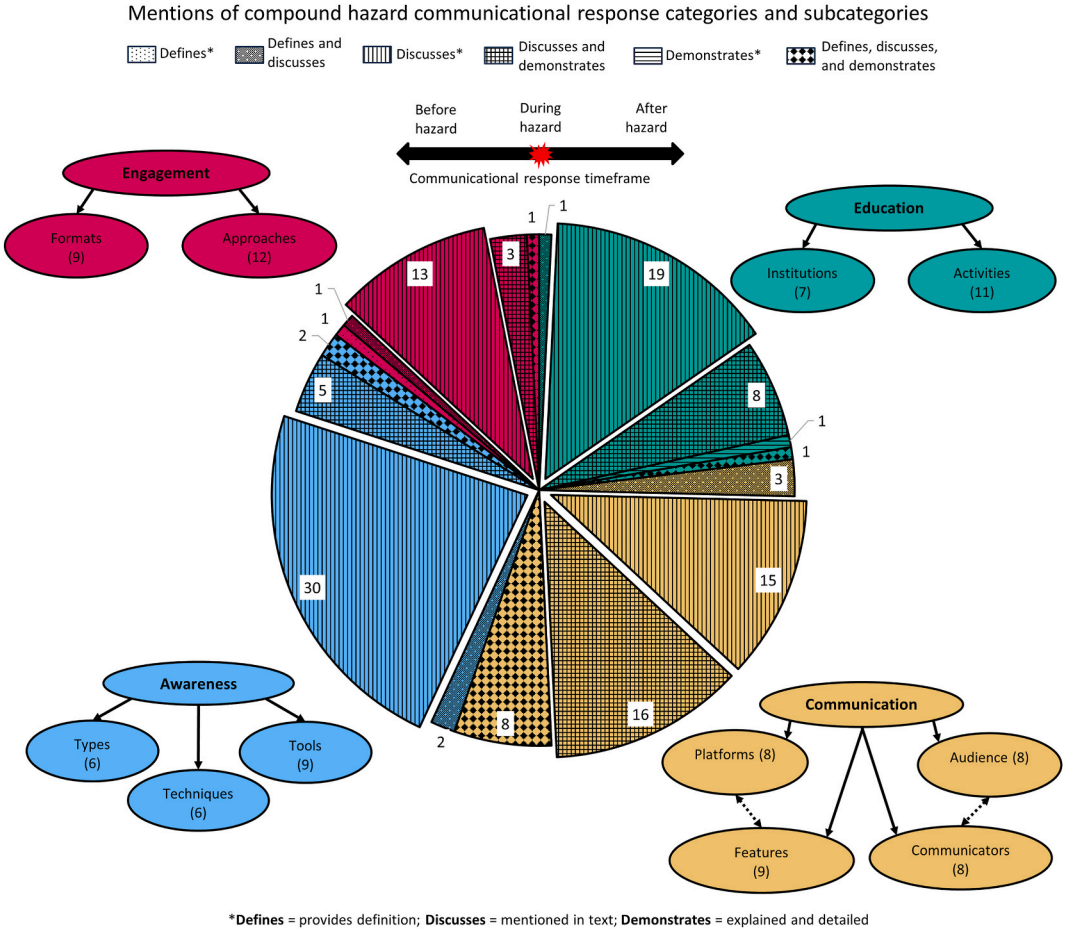


Fig. 9. Compound hazard communicational responses as identified in studies, with each category (i.e., education, communication, awareness, and engagement) and the number of distinct interventions (in parentheses). Each category mention was assessed for being defined, where authors provide a definition, discussed, where authors mention the subcategories in the text, and demonstrated, where authors explain and detail the strategies. Additionally, all communicational response categories were aligned with their timeframe around compound hazards (i.e., before, during, or after), where interventions could be identified as crossing multiple timeframes.

education activities were less common than expected (Table 2). Governments were more likely to use education campaigns, while education programs were typically linked to disaster preparedness, risk reduction, and community-based education.

5.2.6. Communication

Communication strategies most frequently occurred before hazards (81 %) and were also common during hazards (20 studies mentioned) of the 42 studies discussing the category (Fig. 10). Commonly mentioned platforms for communication were social media (19), telephone/SMS (18), warning messages (17), and public media like TV (17). The primary features of communication activities were trust in communicators (25), communication between stakeholders (16), and virtual/online communications (13). The need for translation of communication outputs into relevant community languages also featured prominently (9). Local residents (26) and the general public (24) were described as the most common audience for the communication strategies and government agencies (30), emergency management agencies (11), and trained communicators (8) were the primary communicators mentioned.

5.2.7. Awareness

Awareness-building practices were most frequently mentioned as needing to occur before hazards (79 %) yet were also identified as occurring during (14 studies mentioned) and after (10) hazards for the 39 studies discussing awareness (Fig. 11). The most common types of awareness-building practices were diverse sources of information (23), resilience awareness (21), risk perception/identification (17), and community preparedness (16). The most frequent tools were general knowledge sharing (12), training courses/counselling (11), and web-delivered information/webinars (10). The most common techniques or approaches to awareness are social vulnerability-focused (15), general awareness campaigns (11), and participatory approaches (9).

5.2.8. Engagement

Engagement strategies were similarly mentioned as occurring before hazards (78 %) for the 18 studies discussing engagement (Fig. 12). This was the least frequently discussed category (see Fig. 10). Capacity building programs (4), as well as programs like community engagement (3), risk reduction (3), and emergency management campaigns (3), were the most common engagement approaches; however, engagement approaches were relatively sparsely referred to across the studies. In some cases, engagement was mentioned, yet the approach discussed was a type of education or communication initiative (e.g., describing a "community engagement activity" to educate a community about disaster preparedness). Engagement formats, or the general design of the engagement approach, were discussed more frequently, with the most common being community-agency partnerships (11), agency strategic (8), and co-produced/co-designed engagement (6).

5.2.9. Tools

Focusing on studies that had specific learnings for communicational responses, all studies (45) mentioned using specific tools or associated strategies as tools (Table 3). While some of these tools are not explicit strategies, as above, (e.g., early warning systems), they played a significant role in how studies described compound hazard scenarios. Less than a third of studies (29 %) defined what a 'tool' was in the context of the scenario, while around half of the studies (51 %) demonstrated the specific use of the tool. Early warning systems (23 mentions) and evacuation plans (22) were the most frequently mentioned tools.

6. Discussion

We identified several trends significant to understanding communicational responses to compound natural hazards using a structured theoretical-based literature review process. Notably, we detected an increasing number of papers over time, which indicates that compound hazard communication and engagement is a growing area of research interest. This increased scholarly attention aligns with the increased likelihood in our changing climate that compound hazard events will occur [51], however it is significant that only 29 % of papers reviewed made an explicit link to climate change. This apparent reluctance by researchers to identify climate change as the cause of increasing compound hazard events is in itself a surprising finding and an indication that further research on compound hazards in the context of climate change is needed. We also note the need for more studies focusing on compound natural hazards in the Global South, particularly Africa and Latin America, given the greater vulnerability of many Global South nations to hazards impacts [52–55].

Importantly, our analysis reveals inconsistencies in the reviewed literature on the definition of compound hazards. There is no consensus among researchers on how to describe or name a compound hazard; indeed, multiple terms are often used interchangeably to refer to such events (see Fig. 8). The connotations of these labels and their impacts on the research are rarely discussed. For example, the term "compound" highlights the compounding or exacerbating factors of multiple disasters in a way that terms like "multiple" do not. We identified some confusion in the usae of the term "multi-hazard", which is commonly deployed to refer to compound or cascading hazards, but can also refer to the individual assessment of multiple types of hazards that do not occur simultaneously or in quick sucession. Furthermore, while it is clear that compound hazards comprise a complex and overlapping temporality, challenging what Jackson describes as the "mainstream view" that "disasters are discrete events" that can be easily bounded [56], there is no agreed-upon definition of the temporal scale between the two hazards that constitute a compound hazard.This is further complicated by a lack of clear understanding about when hazards begin and end. Some studies refer to compound hazards in an indirect way, acknowledging that hazards can be compound without making the compound nature of the hazards a focus of the research. In this sense, the concept of hazards as 'compound' is at times an undercurrent of the research rather than a focal point, and while it is increasingly acknowledged that hazards *are* often compound, multiple, or overlapping, the implications of this are not always explored

Table 2
Total mentions of educational strategies by institution type out of 29 studies.

Institutions									
(*Totals by category*) Coinciding mentions[a]			Education program	Governments	Emergency management agencies	School-based education	University/higher education	Partner organization	Unclassified
			(15)	(12)	(5)	(5)	(5)	(4)	(3)
Education activity	Disaster preparedness education	***(14)***	6	6	2	3	4	2	1
	Workshops/seminars/ trainings	***(12)***	5	4	3	2	4	2	1
	Risk reduction program	***(10)***	6	2	3	3	3	1	1
	Community-based education	***(9)***	6	4	3	2	2	2	0
	Scenario work	***(7)***	4	2	0	2	3	2	1
	Education campaign	***(6)***	3	6	2	2	2	3	0
	Learn from impacted communities	***(5)***	4	2	2	3	2	2	0
	Lesson plan/curricula	***(3)***	3	1	0	2	2	1	0
	GIS tool/interactive maps	***(3)***	3	2	1	2	1	2	0
	Games/movies	***(2)***	2	2	1	1	1	2	0
	Citizen science-based education	***(2)***	1	1	0	1	2	2	0

[a] Indicates mentions of institutions and activities within a study, where line totals are greater than category totals due to studies mentioning multiple institutions and activities.

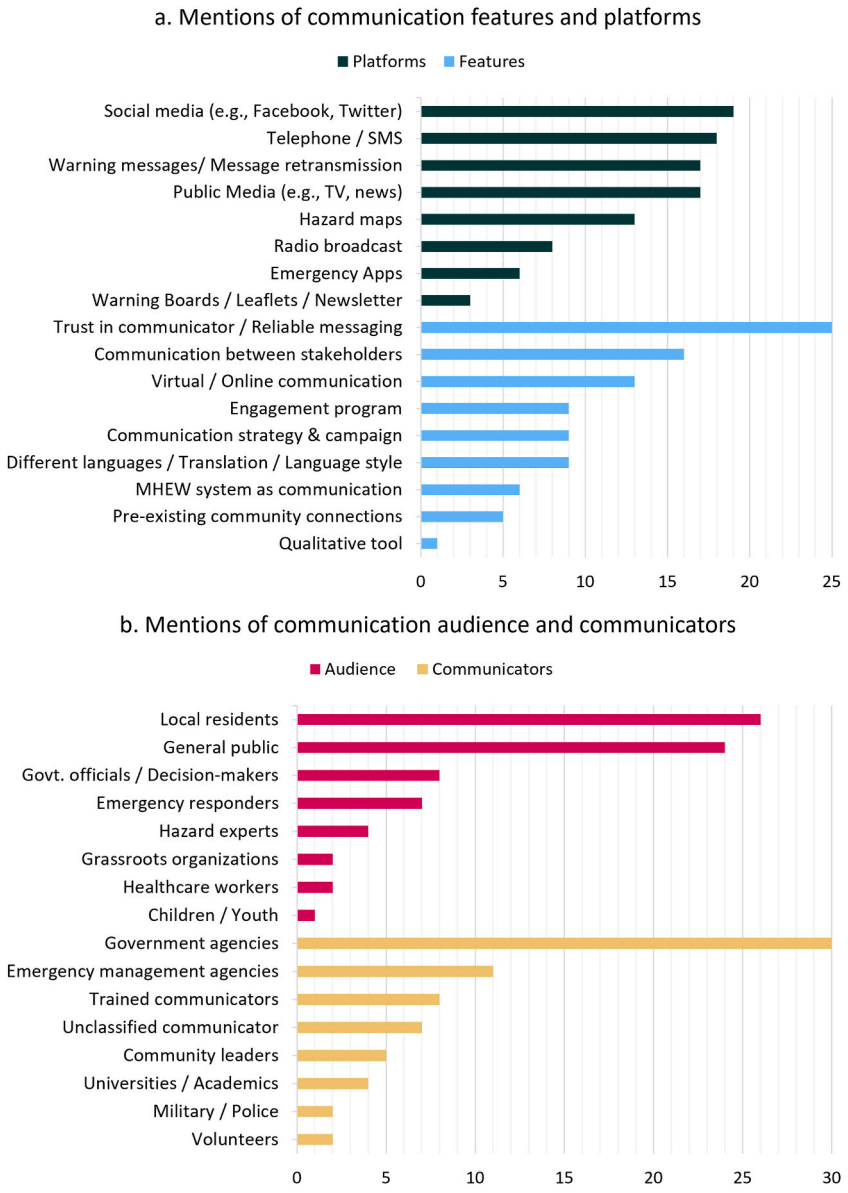


Fig. 10. Mentions of communication strategies: a. features and platforms and b. audience and communicators out of 42 studies discussing communication.

in depth. This lack of consensus on terminology is itself a significant finding of this study because it causes confusion and poses a challenge to disaster communication at both in the realm of research and at an operational level.

The studies in our sample came from a variety of disciplinary perspectives. Given that our review focused on *communicational* responses to compound hazards, it is significant that we detected only two studies from journals specific to the discipline of communication. Perhaps for this reason, across the studies reviewed, there was little explicit definition of communication, awareness, and education as responses to compound natural hazards, although such responses to hazards were presented as crucial. Definitions were instead often implied. For example, López-Saavedra et al. [48], Dallo & Marti [57], and Burston et al. [58] discussed and demonstrated communication but did not define its meaning. Communication was commonly understood to involve the sharing of information with audiences consisting mainly of local residents and/or the general public. Awareness was seen to encompass resilience awareness and risk perception. Education, meanwhile, was shown to occur in both formal and informal settings with a focus on disaster preparedness and risk reduction. In the papers reviewed, there were mentions of engagement approaches and activities that combine elements of communication, education, and awareness. Community engagement forums and citizen science initiatives are two examples of practices that fell under our "engagement" banner but nevertheless involve aspects of communication, education, and awareness. A crucial finding of this review is that while communicational responses are essential, there is no existing framework or

Fig. 11. Mentions of awareness-building practices by type, tool, and technique; noting that these categories are not mutually exclusive.

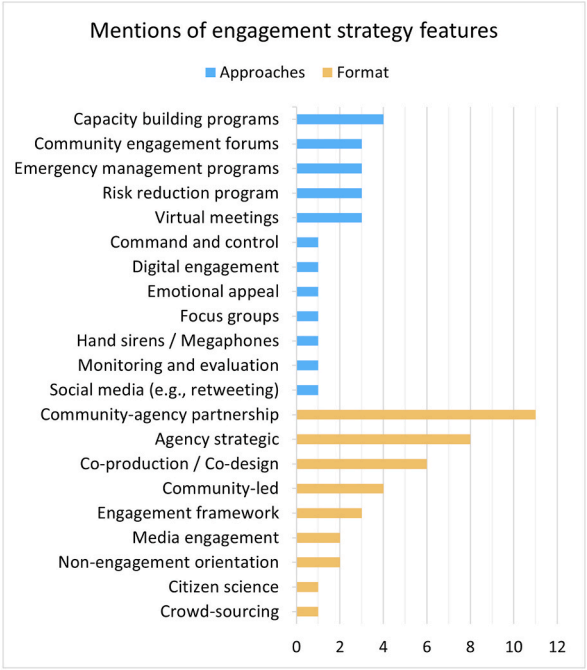


Fig. 12. Mentions of engagement approach and format, where categories are not mutually exclusive.

protocol for communication, education, engagement and/or awareness before, during, or after compound natural hazards.

This review also identified a range of tools through which communication, education, and awareness-based responses to compound natural hazards can be implemented. Social media, text messages, and public media were commonly identified as communication

Table 3
Mentions of tools across all studies (n = 45), where some data has appeared in previous sections.

Author-described tools	Number of mentions
Early Warning System (EWS)	23
Evacuation plans & measures	22
Multi-hazard mapping	20
Simulations/modelling	19
Web platforms/apps	13
Forecasting tool	11
Scenario planning	8
Multi-risk analysis tool	6
Diagnostic tool	5
Classification scheme	3
Spatial dashboard	3
Risk financing	2

tools, while knowledge-sharing events, training, and webinars were identified as tools for spreading awareness. Early warning systems were regularly mentioned as a major tool in the compound hazard space. Multi-hazard mapping also received attention as an important step towards understanding and responding to compound hazards. In this sense, there is an awareness in the existing scholarship of the rich opportunities and affordances associated with a complex and evolving communication landscape, with its multiple channels and communication tools. Importantly, though, little attention was paid to the *distinct* communication, education, or awareness practices that should be employed during *compound* natural disasters (as opposed to discrete or one-off disasters), or to the ways in which communication might be tailored to suit compound hazard situations. We propose that this is an underexplored area and that there is an imperative for future research to identify communicational approaches that consider the compound nature of the disaster and related factors like community fatigue and recovery periods.

Across the 45 articles reviewed, there was clear consensus about the main actors who deliver communication, education, and awareness-based responses. Government bodies at all scales were described as the main communicators and governments, in addition to government-sponsored programs, were seen to be driving education-based initiatives. Non-government agencies were seen to play a role in engagement activities, and where the focus was on engagement (involving a mix of communication, education, and/or awareness-raising) community-agency partnerships were important. Trust was flagged as the most important feature of communication, which means that levels of trust in government are likely an indicator of the success of a communicational response to compound natural hazards.

We found that particularly education, but also communication and awareness-building, were presented in the literature in a way that evokes the information deficit model of science communication [59]. There was little acknowledgement in the reviewed literature of the problems with this model or of potential community pushback on educational initiatives, especially those that treat community members as deficient or lacking [9,60,61]. In this context, we found a tendency to depict communication, education, and awareness as activities that are *done to* (rather than *done with*) communities, this, despite the fact that the literature in hazard communication has long recommended moving decisively away from the one-way, deficit model of communication [60]. Several papers included in this SQLR did propose that reciprocal communication between stakeholders was more productive than a top-down approach, suggesting a recognition of the need for multidirectional, participatory models of communication for compound natural hazards. W [59].

Finally, the papers reviewed here commonly referred to communication, education, or awareness-building as activities that occurred *before* a hazard, rather than during or after a hazard. This is significant as it implies a definition of communicational responses to compound hazards that centres on preparedness and risk reduction. While preparedness is critically important, we contend that further research is needed on the role of communicational responses while compound disasters are occurring, including tailored warnings for compound hazards, and during recovery periods. The natural hazards literature more broadly has found that in recovery in particular, creative communication and practices can help communities build resilience [62,63], but the literature included in the SQLR did not shed any light on creative recovery communication for compound hazards, setting this up as another research gap in relation to communicating such hazards. One study, published after this SQLR's timeframe, in 2024, has similarly highlighted how creative and participatory communication in post-disaster settings "can variously be part of the healing exercise, a way to gather insights into what worked and what went wrong, or explorations about future pathways for community recovery and renewal." [64].

7. Limitations

Not all papers within search results on Google Scholar could be included and assessed. A challenge was posed by the fact that the number of papers relating to 'compound hazards' alone was relatively limited, while together with the expanded search terms, the number of results was large. Because of the study scope and timeframe, we needed to set exclusion criteria, meaning we did not include most of the theses or dissertations that came up in our research. Many other papers were excluded on thorough assessment as not focusing substantially on the search terms. Importantly, we decided to exclude grey literature from the SQLR because of difficulty with systematising a search of such non-peer reviewed literature. To scope the grey literature, we undertook a separate non-systematic review as background to our broader research. We concluded that use of the term 'compound hazard' is quite rare in a selection of technical and policy reports from different global locations, written in English, with no reports that prominently addressed our

'communicational responses', as described, to compound hazards. It is acknowledged that the SQLR process provides a snapshot of research at the time of execution. Therefore, as this paper targets a set timeframe, it does not reflect research published beyond October 2023. However, it is expected that literature will continue to be published on this topic in the coming years due to its high relevance in the current context.

8. Future research

Opportunities exist for further investigation of compound natural hazard responses specifically from the perspective of communication research. It is imperative for future research to identify communicational responses that consider the compound nature of the disaster and related factors like community fatigue and recovery periods. Future research might additionally focus on 'grey literature' including emergency management and natural hazard policy documentation to better understand how hazard communication is being done currently, and how this might be adapted for compound hazards. It is also essential for researchers to engage with communities to understand directly from them their experiences of communication in compound hazard contexts and to listen to their needs.

As this review shows, there is also no existing framework or protocol for communication, education, engagement and/or awareness before, during, or after compound natural hazards. Further research is therefore clearly needed on the role of communicational responses while compound disasters are occurring and during recovery periods, not just in the preparation phase of the disaster cycle. This paper also opens important avenues for further research into risk management and governance in relation to compound natural hazards. While these are beyond the scope of the current paper, it is clear that in order to better govern compound hazard risk, the communicational aspects of these hazards must be closely attended to in future research into governance.

9. Conclusion

Compound events are already a lived experience for many people around the world, whether they recognise this or not. As a team of Australian researchers, we live on a landmass already substantially affected by such hazards. However, we are aware that the need to communicate about and prepare for compound hazards has only recently started to be discussed by risk and emergency management agencies in our own national context. It is now imperative to make clear to communities, globally, the accelerating likelihood, under climate change, of experiencing compound hazards. Authorities charged with managing hazards must therefore clearly understand the current research landscape and establish a nationally accepted practice on communicational responses to compound hazards, as a starting place for engaging communities and individuals in awareness and preparedness action. Such authorities also need a clear understanding of "what works" in terms of emergency communication pathways and strategies *during* events, and what kind of information is needed – by what means – *after* events, to enable recovery. This is a complex, multi-directional landscape of numerous platforms and channels, with multiple stakeholders, across spatio-temporal scales. It is clear that what we characterise here as *communicational responses* substantially underpin the whole gamut of actions necessary to reduce risk from compound hazards. Recognising this is just a first step. We contend that to further build capability and catalyse protective action, emergency managers must consult closely with communities, listening and exchanging knowledge, to build together strategies that support communities' and individuals' preparedness, survival and recovery in a time of increasing compound hazard risk.

CRediT authorship contribution statement

Noelle Nemeth: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Malcolm S. Johnson:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Gabi Mocatta:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Data curation, Conceptualization. **Erin Hawley:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Gabi Mocatta and Erin Hawley reports financial support was provided by Natural Hazards Research Australia. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was funded by Natural Hazards Research Australia, as project: 'T2-A1 Awareness, Education and Communication for Compound Natural Hazards'.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2024.105041.

Data availability

We have shared a supplementary file containing data

References

[1] F.E.L. Otto, S. Philip, S. Kew, S. Li, A. King, H. Cullen, Attributing high-impact extreme events across timescales—a case study of four different types of events, Climatic Change 149 (3–4) (2018 Aug) 399–412.

[2] IPCC, in: V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B. R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (Eds.), Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty, 1, Cambridge University Press, 2018 [cited 2024 Apr 13]. Available from: https://www.ipcc.ch/sr15/.

[3] National Disaster Risk Reduction Framework, Australian Government, Internet, Department of Home Affairs, 2018. Available from: https://www.homeaffairs.gov.au/emergency/files/national-disaster-risk-reduction-framework.pdf.

[4] C.B. Field, V. Barros, T.F. Stocker, Q. Dahe (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change [Internet], Cambridge University Press, Cambridge, 2012 [cited 2024 Apr 13]. Available from: http://ebooks.cambridge.org/ref/id/CBO9781139177245.

[5] B. Fakhruddin, H. Clark, L. Robinson, L. Hieber-Girardet, Should I stay or should I go now? Why risk communication is the critical component in disaster risk reduction, Prog Disaster Sci. 8 (2020 Dec) 100139.

[6] S. Hansson, K. Orru, A. Siibak, A. Bäck, M. Krüger, F. Gabel, et al., Communication-related vulnerability to disasters: a heuristic framework, Int. J. Disaster Risk Reduc. 51 (2020 Dec 1) 101931.

[7] UNDRR. Sendai Framework for Disaster Risk Reduction [Internet]. United Nations Office for Disaster Risk Reduction (UNDRR); 215AD p.32. Available from: https://www.unisdr.org/we/inform/publications/43291.

[8] P. Satizábal, I. Cornes, M. de Lourdes Melo Zurita, B.R. Cook, The power of connection: navigating the constraints of community engagement for disaster risk reduction, Int. J. Disaster Risk Reduc. 68 (2022 Jan 1) 102699.

[9] B.R. Cook, M.D.L. Melo Zurita, Fulfilling the promise of participation by not resuscitating the deficit model, Global Environ. Change 56 (2019 May) 56–65.

[10] M. Bucchi, Of deficits, deviations and dialogues: theories of public communication of science, in: Handbook of Public Communication of Science and Technology, Routledge, 2008.

[11] Australian Institute for Disaster Resilience, Community engagement for disaster resilience [Internet], Available from: www.knowledge.aidr.org.au/resources/handbook-community-engagement, 2020.

[12] S. Fazeli, M. Haghani, M. Mojtahedi, T.H. Rashidi, The role of individual preparedness and behavioural training in natural hazards: a scoping review, Int. J. Disaster Risk Reduc. 105 (2024 Apr) 104379.

[13] K.A. Johnston, M. Taylor, B. Ryan, Engaging communities to prepare for natural hazards: a conceptual model, Nat. Hazards 112 (3) (2022 Jul) 2831–2851.

[14] A. Gissing, M. Timms, S. Browning, R. Crompton, J. McAneney, Compound Natural Disasters in Australia: a Historical Analysis, Internet, Bushfire and Natural Hazards CRC, Melbourne, 2020. Available from: https://www.bnhcrc.com.au/sites/default/files/managed/downloads/bnhcrc_compound_disaasters_report_final.pdf.

[15] R. Dawkins, How to Build Resilience in the Face of Compounding Extreme Events [Internet]., CSIRO, 2022 Apr. Available from https://www.csiro.au/en/news/all/articles/2022/april/compound-risk-extreme-events.

[16] Angeli S. De, B.D. Malamud, L. Rossi, F.E. Taylor, E. Trasforini, R. Rudari, A multi-hazard framework for spatial-temporal impact analysis, Int. J. Disaster Risk Reduc. 73 (2022 Apr 15) 102829.

[17] K. Barquet, M. Englund, K. Inga, K. André, L. Segnestam, Conceptualising multiple hazards and cascading effects on critical infrastructures, Disasters 48 (1) (2024 Jan) e12591.

[18] D.E. Alexander, G. Pescaroli, The role of translators and interpreters in cascading crises and disasters: towards a framework for confronting the challenges, Disaster Prev. Manag. 29 (2) (2019 Jan 1) 144–156.

[19] E. Borowski, A. Stathopoulos, Protection or peril of following the crowd in a pandemic-concurrent flood evacuation, Nat. Hazards Rev. 24 (1) (2023 Feb 1) 04022045.

[20] H.D. O'Hair, M.J. O'Hair, Communication and Catastrophic Events: Strategic Risk and Crisis Management 1 (2022). Communication and Catastrophic Events: Strategic Risk and Crisis Management.

[21] J. Paul, P. Khatri, H. Kaur Duggal, Frameworks for developing impactful systematic literature reviews and theory building: what, Why and How? J. Decis. Syst. 33 (4) (2024 Oct 1) 537–550.

[22] A. Gissing, M. Timms, S. Browning, R. Crompton, J. McAneney, Compound natural disasters in Australia: a historical analysis, Environ. Hazards 21 (2) (2022 Mar 15) 159–173.

[23] M.S. Kappes, M. Keiler, K. Von Elverfeldt, T. Glade, Challenges of analyzing multi-hazard risk: a review, Nat. Hazards 64 (2) (2012 Nov) 1925–1958.

[24] O. Drakes, E. Tate, Social vulnerability in a multi-hazard context: a systematic review, Environ. Res. Lett. 17 (3) (2022 Mar 1) 033001.

[25] S. Seneviratne, N. Nicholls, D. Easterling, C. Goodess, S. Kanae, J. Kossin, et al., Changes in climate extremes and their impacts on the natural physical environment [cited 2024 Apr 13]; Available from: https://academiccommons.columbia.edu/doi/10.7916/d8-6nbt-s431, 2012.

[26] J.N. Claassen, P.J. Ward, J. Daniell, E.E. Koks, T. Tiggeloven, M.C. De Ruiter, A new method to compile global multi-hazard event sets, Sci. Rep. 13 (1) (2023 Aug 23) 13808.

[27] J. Kloos, D. Asare-Kyei, J. Pardoe, F.G. Renaud, Towards the development of an adapted multi-hazard risk assessment framework for the west sudanian savanna zone [cited 2024 Apr 13]. (UNU-EHS Publication Series). Report No.: 11. Available from: https://www.academia.edu/72497774/Towards_the_Development_of_an_Adapted_Multi_hazard_Risk_Assessment_Framework_for_the_West_Sudanian_Savanna_Zone, 2015 Jan.

[28] F. Sakahira, U. Hiroi, Designing cascading disaster networks by means of natural language processing, Int. J. Disaster Risk Reduc. 66 (2021 Dec) 102623.

[29] J. Wang, Z. He, W. Weng, A review of the research into the relations between hazards in multi-hazard risk analysis, Nat. Hazards 104 (3) (2020 Dec) 2003–2026.

[30] F.E.L. Otto, E. Raju, Harbingers of decades of unnatural disasters, Commun Earth Environ 4 (1) (2023 Aug 7) 1–7.

[31] E. Pawson, Environmental hazards and natural disasters, N. Z. Geogr. 67 (3) (2011) 143–147.

[32] K.A. Sullivan-Wiley, Short gianotti AG. Risk perception in a multi-hazard environment, World Dev. 97 (2017 Sep 1) 138–152.

[33] Ö. Bodin, D. Nohrstedt, K. Orach, A diagnostic for evaluating collaborative responses to compound emergencies, Progress in Disaster Science 16 (2022 Dec) 100251.

[34] M. Cook, E. Harrison, Ten years on: brisbane's compounding flood risk, in: A. Lukasiewicz, T. O'Donnell (Eds.), Complex Disasters [Internet], Springer Nature Singapore, Singapore, 2022, pp. 101–121 (Disaster Risk, Resilience, Reconstruction and Recovery). Available from: https://link.springer.com/10.1007/978-981-19-2428-6_6.
[35] D.P. Rogers, L. Anderson-Berry, A.M. Bogdanova, G. Fleming, H. Gitay, S. Kahandawa, et al., COVID-19 and lessons from multi-hazard early warning systems, Adv. Sci. Res. 17 (2020 Jul 13) 129–141.
[36] Y.C. Lin, G. Mestav Sarica, T.J. Chua, A.B. Stone, S.F. Jenkins, A.D. Switzer, et al., Characterizing drivers of asia's black elephant disaster risks, Earth's Future 10 (12) (2022 Dec) e2021EF002607.
[37] S. Segoni, L. Piciullo, S.L. Gariano, A review of the recent literature on rainfall thresholds for landslide occurrence, Landslides 15 (8) (2018 Aug) 1483–1501.
[38] D. Green, J. Whitney, Public hazard awareness for culturally and linguistically diverse communities during protracted events: a case study of Japan's pandemic response, in: A. Lukasiewicz, T. O'Donnell (Eds.), *Complex Disasters [*Internet], Springer Nature Singapore, Singapore, 2022, pp. 217–239 (*Disaster Risk, Resilience, Reconstruction and Recovery*). Available from: https://link.springer.com/10.1007/978-981-19-2428-6_12.
[39] M. Abunyewah, T. Gajendran, K. Maund, S.A. Okyere, Strengthening the information deficit model for disaster preparedness: mediating and moderating effects of community participation, Int. J. Disaster Risk Reduc. 46 (2020 Jun) 101492.
[40] A.S. Dietrich, On seeing and listening: how to better support affected communities before the disaster starts, Int. J. Mass Emergencies Disasters 38 (1) (2020) 13–42.
[41] OECD, Policy handbook on natural hazard awareness and disaster risk reduction education, Available from: https://www.oecd.org/finance/insurance/42221773.pdf, 2010.
[42] P.C. Cisternas, L.A. Cifuentes, N.C. Bronfman, P.B. Repetto, The influence of risk awareness and government trust on risk perception and preparedness for natural hazards, Risk Anal. 44 (2) (2024 Feb) 333–348.
[43] A. Ivčević, R. Bertoldo, H. Mazurek, L. Siame, S. Guignard, A. Ben Moussa, et al., Local risk awareness and precautionary behaviour in a multi-hazard region of North Morocco, Int. J. Disaster Risk Reduc. 50 (2020 Nov 1) 101724.
[44] C. Pickering, M.S. Johnson, J. Byrne, Using systematic quantitative literature reviews for urban analysis, in: S. Baum (Ed.), *Methods in Urban Analysis* [Internet], Springer, Singapore, 2021, pp. 29–49, https://doi.org/10.1007/978-981-16-1677-8_3 (Cities Research Series).
[45] C. Pickering, J. Byrne, The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers, High Educ. Res. Dev. 33 (3) (2014 May 4) 534–548.
[46] D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, T.P. Group, Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, PLoS Med. 6 (7) (2009 Jul 21) e1000097.
[47] N.P. Simpson, P.A. Williams, K.J. Mach, L. Berrang-Ford, R. Biesbroek, M. Haasnoot, et al., Adaptation to compound climate risks: a systematic global stocktake, iScience 26 (2) (2023 Feb 17) 105926.
[48] M. López-Saavedra, J. Martí, L. Planagumà, How effective risk assessment and management is the key to turning volcanic islands into a source of nature-based solutions, Land 12 (3) (2023 Mar 15) 686.
[49] C.H. Lai, P.C. Liao, S.H. Chen, Y.C. Wang, C. Cheng, C.F. Wu, Risk perception and adaptation of climate change: an assessment of community resilience in rural Taiwan, Sustainability 13 (7) (2021 Mar 25) 3651.
[50] J.C. Gill, B.D. Malamud, E.M. Barillas, A. Guerra Noriega, Construction of regional multi-hazard interaction frameworks, with an application to Guatemala, Nat. Hazards Earth Syst. Sci. 20 (1) (2020 Jan 14) 149–180.
[51] V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, et al. (Eds.), *Climate Change 2021: the Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the, IPCC. Cambridge University Press, 2021.
[52] D. Haelewaters, T.A. Hofmann, A.L. Romero-Olivares, Ten simple rules for Global North researchers to stop perpetuating helicopter research in the Global South, PLoS Comput. Biol. 17 (8) (2021 Aug 19) e1009277.
[53] D. Mills, K. Inouye, Problematizing 'predatory publishing': a systematic review of factors shaping publishing motives, decisions, and experiences, Learn. Publ. 34 (2) (2021) 89–104.
[54] S. Haug, J. Braveboy-Wagner, G. Maihold, The 'Global South' in the study of world politics: examining a meta category, Third World Q. 42 (9) (2021 Sep 2) 1923–1944.
[55] C.M. Baum, L. Fritz, S. Low, B.K. Sovacool, Public perceptions and support of climate intervention technologies across the Global North and Global South, Nat. Commun. 15 (1) (2024 Mar 6) 2060.
[56] G. Jackson, Perceptions of disaster temporalities in two Indigenous societies from the Southwest Pacific, Int. J. Disaster Risk Reduc. 57 (2021 Apr 15) 102221.
[57] I. Dallo, M. Marti, Why should I use a multi-hazard app? Assessing the public's information needs and app feature preferences in a participatory process, Int. J. Disaster Risk Reduc. 57 (2021 Apr 15) 102197.
[58] J. Burston, D. Ware, R. Tomlinson, The real-time needs of emergency managers for tropical cyclone storm tide forecasting: results of a participatory stakeholder engagement process, Nat. Hazards 78 (3) (2015 Sep 1) 1653–1668.
[59] T. Bubela, M.C. Nisbet, R. Borchelt, F. Brunger, C. Critchley, E. Einsiedel, et al., Science communication reconsidered, Nat. Biotechnol. 27 (6) (2009 Jun) 514–518.
[60] M.J. Simis, H. Madden, M.A. Cacciatore, S.K. Yeo, The lure of rationality: why does the deficit model persist in science communication? Publ. Understand. Sci. 25 (4) (2016 May) 400–414.
[61] P. Sturgis, N. Allum, Science in society: Re-evaluating the deficit model of public attitudes, Publ. Understand. Sci. 13 (1) (2004 Jan 1) 55–74.
[62] S. Mackay, E. Ellison, W. Bennett, Natural disaster resilience and the creative arts: a case study from rural Australia, J. Arts Communities 15 (1) (2024 Apr 1) 57–73.
[63] A. Liguori, K. Le Rossignol, S. Kraus, L. McEwen, M. Wilson, Exploring the uses of arts-led community spaces to build resilience: applied storytelling for successful Co-creative work, Journal of Extreme Events 9 (1) (2022 Mar) 2250007.
[64] I.S. Stewart, Advancing disaster risk communications, Earth Sci. Rev. (2024) 104677.