AGU PUBLICATIONS

Earth's Future

COMMENTARY
10.1002/2017EF000764

Special Section:
Avoiding Disasters: Strengthening Societal Resilience to Natural Hazards

Key Points:
- Economic losses caused by natural hazards are increasing in many regions of the world
- We propose an integrative research framework that specifies the scope of enquiry, concepts, and general relations among phenomena
- We identify three empirical puzzles as examples of crucial areas where more knowledge is needed

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Citation:
Di Baldassarre, G., Nohrstedt, D., Mård, J., Burchardt, S., Albin, C., Bondesson, S., Breinl, K., Deegan, F. M., Fuentes, D., Lopez, M. G., Granberg, M., Nyberg, L., Nyman, M. R., Rhodes, E., Troll, V., Young, S., Walch, C., & Parker, C. F. (2018). An Integrative Research Framework to Unravel the Interplay of Natural Hazards and Vulnerabilities, *Earth's Future*, *6*, 305–310. https://doi.org/10.1002/2017EF000764

Received 21 NOV 2017
Accepted 18 FEB 2018
Accepted article online 22 FEB 2018
Published online 14 MAR 2018

An Integrative Research Framework to Unravel the Interplay of Natural Hazards and Vulnerabilities

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Abstract Climate change, globalization, urbanization, social isolation, and increased interconnectedness between physical, human, and technological systems pose major challenges to disaster risk reduction (DRR). Subsequently, economic losses caused by natural hazards are increasing in many regions of the world, despite scientific progress, persistent policy action, and international cooperation. We argue that these dramatic figures call for novel scientific approaches and new types of data collection to integrate the two main approaches that still dominate the science underpinning DRR: the hazard paradigm and the vulnerability paradigm. Building from these two approaches, here we propose a research framework that specifies the scope of enquiry, concepts, and general relations among phenomena. We then discuss the essential steps to advance systematic empirical research and evidence-based DRR policy action.

Plain Language Summary The recent deadly earthquake in Iran-Iraq has been yet another reminder of the topicality of natural hazards, and it has come just after an unprecedented series of catastrophic events, including the extensive flooding in South Asia and the string of devastating hurricanes in the Americas. He we identify three main puzzles in the nexus of natural hazards and vulnerabilities, and demonstrate how novel approaches are needed to solve them with reference to a flood risk example. Specifically, we show how a new research framework can guide systematic data collections to advance the fundamental understanding of socionatural interactions, which is an essential step to improve the development of policies for disaster risk reduction.

1. Premise

Climate change, globalization, urbanization, social isolation, and increased interconnectedness between physical, human, and technological systems (Cutter et al., 2015) pose major challenges to disaster risk reduction (DRR). Subsequently, economic losses caused by natural hazards are increasing in many regions of the world (Figure 1), despite scientific progress, persistent policy action, and international cooperation (United Nations [UN], 2015).

We argue that these dramatic figures call for novel scientific approaches and new types of data collection to integrate the two main approaches that still dominate the science underpinning DRR: the hazard paradigm and the vulnerability paradigm (Blöschl et al., 2013). Building from these two approaches, here we propose a research framework that specifies the scope of enquiry, concepts, and general relations among phenomena (Ostrom, 2009). We then discuss the essential steps to advance systematic empirical research and evidence-based DRR policy action.

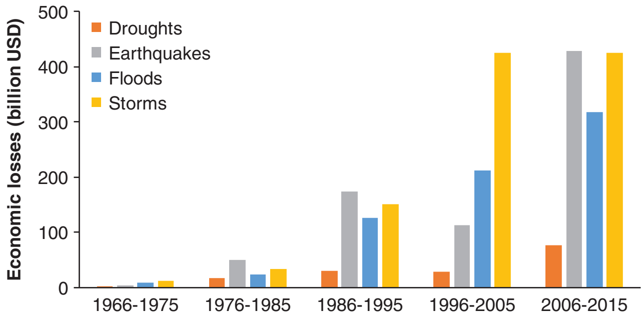

Figure 1. Global trends of economic losses (billion USD) over the past decades. Data from EM-DAT: The Emergency Events Database—Université catholique de Louvain (UCL)—CRED, D. Guha-Sapir, www.emdat.be, Brussels, Belgium.

The hazard paradigm emphasizes the study of the natural processes that trigger disasters. It typically suggests solutions to reduce their impacts on exposed people, assets, and critical infrastructures (Blöschl et al., 2013). This paradigm underpins quantitative assessments of disaster risk, broadly defined as a combination of the probability of extreme events and their potential adverse consequences. When estimating the effects of structural measures to reduce hazard levels, this paradigm often overlooks societal responses that can produce unintended consequences. For instance, the safe-development paradox (Burby, 2006) shows that lowering hazard levels can paradoxically lead to increased risks, as doing so can reduce risk awareness and promote urban expansion in disaster-prone areas (Kates et al., 2006). In flood risk management, for example, it has been shown that raising levees can increase the potential adverse consequences of flooding (Di Baldassarre et al., 2015). Catastrophic losses and fatalities in New Orleans (2005), Brisbane (2011), and Houston (2017) are related to the urbanization of floodplain areas facilitated by the presence of structural flood protection.

The vulnerability paradigm focuses on social and technical factors that shape vulnerability. In this paradigm, DRR measures target the conditions that make communities more vulnerable, for instance poverty or fragile infrastructures (Wisner et al., 2003). In this view, exposure to disaster risk is a product of power imbalances and inequality, affecting predominantly marginalized communities (Gaillard & Mercer, 2013). Proponents of the vulnerability paradigm avoid hazard predictions, which are associated with known limitations especially in relation to multihazards with cascading effects or disasters. Examples include the 2011 triple disaster in Japan, that is, earthquake followed by tsunami and meltdown at the Fukushima power plant (Pescaroli & Alexander, 2015), and the 1953 Tangiwai rail disaster in New Zealand, that is, collapse of an instable crater lake wall on Mount Ruapehu led to a mudflow (lahar), which took out a rail bridge and led to a fatal train derailing (Johnston et al., 2000). Yet, the vulnerability paradigm often overlooks that social and technical conditions that make individuals, communities and infrastructures vulnerable vary across different types of natural hazards. As a result, this paradigm cannot explain unexpected successes, such as long-term adaptation processes associated with repeated events. For example, while Bangladesh is one of the poorest countries in the world with weak infrastructures and fragile political institutions, flood resilience has been developed through a variety of formal and informal measures, including temporary migration. As a result, flood fatalities have been significantly reduced in Bangladesh over the past 40 years (Kreibich et al., 2017).

2. Key Puzzles

Here we identify three empirical puzzles as examples of crucial areas where more fundamental knowledge is needed to advance evidence-based DRR.

2.1. Variability in Learning

The experience of Bangladesh and other unexpected successes (Kreibich et al., 2017) suggest that repeated events, such as floods or cyclones, can promote higher levels of preparedness, or trigger policy change, thereby decreasing fatalities and increasing resilience. Understanding these learning dynamics is important if we are to improve the impact of international cooperative efforts, such as the UN International Strategy for DRR (UN, 2015).

2.2. Diminishing Returns and Unintended Consequences

Effective DRR is often attributed to multistakeholder collaboration, functioning institutions, adaptation, or implementation of risk reduction measures. However, these qualities are difficult to obtain in practice and they can produce unintended effects, such as the safe-development paradox discussed above. These qualities can also generate diminishing returns where efforts to enhance collaboration, for example, do not enhance performance or even lead to negative consequences (Pierce & Aguinis, 2013). Calkin et al. (2015), for instance, have argued that the current wildfire management strategy in the United States can paradoxically increase the risk of future wildfires. Thus, there is a need to understand why these qualities for efficient DRR do not always generate desired outcomes.

2.3. Increase the Visibility of Prevention

Much knowledge of DRR builds from dystopian failure cases, such as hurricane Katrina, where societies have failed to mitigate hazards and risks. Yet, although failure is a potential source of lesson-drawing, history also offers success stories that deserve more rigorous assessment (Adger et al., 2005). Potential cases include positive experiences, such as the empirical evidence of flood risk reduction in multiple sites around the world presented by Kreibich et al. (2017).

3. Elements of a New Framework

We argue that one essential step to further strengthen evidence-based DRR policy-making, and to solve the three puzzles identified above, is to advance the understanding of the feedback mechanisms between natural and social processes by integrating the hazard and vulnerability paradigms. We therefore propose a research framework (Figure 2a) that builds from social-ecological systems (Adger et al., 2005), community resilience (Cutter et al., 2008), climate change adaptation (Birkmann & von Teichman, 2010), and sociohydrology (Sivapalan et al., 2012).

The integrative framework specifies how the impacts and perceptions of natural hazards influence sociotechnical vulnerabilities, governance, and institutions, while at the same time social behavior, technical measures, and policy interventions alter the frequency, magnitude, and spatial distribution of natural hazards (Figure 2a). Reciprocal effects at the local scale are also influenced by global drivers. Climate and environmental change can alter the frequency and severity of extreme weather events, while socioeconomic trends (including population growth, urbanization, and interdependent infrastructures) can increase exposure to natural hazards.

4. Flood Risk Example

To illustrate the underlying logic of the proposed framework, and show how it can help guide empirical and modeling studies to address the three puzzles above, we present an example application in a flood risk setting.

Figure 2b depicts an explanatory model of human-flood interactions, with positive and negative feedback mechanisms between a specific natural hazard, that is, flooding, and elements of vulnerabilities, that is, exposure, risk awareness, wealth, and structural protection measures (levees). This model can be seen as a specification of the more general framework depicted in Figure 2a. Technical, social, demographic, economic, and natural factors influence each other and gradually change overtime, while going through more abrupt change in the wake of flood events (Figure 2b). The model uses change in risk awareness, among policymakers and communities, as a primary mechanism to explain the dynamics of risk. Influenced by the theory of availability heuristics (Tversky & Kahneman, 1973), the model posits that awareness is enhanced immediately after the occurrence of catastrophic events, but then decays overtime (Di Baldassarre et al., 2015).

This model of human-flood interactions can help address the three puzzles as follows.

4.1. Variability in Learning

Adaptation dynamics, such as the one manifested by decreasing flood damage in Bangladesh, are explained by the model as an increase in risk awareness generated by frequent events, which tends to decrease exposure to flooding, and therefore losses (Figure 2b). Yet, there is evidence in other contexts that frequent

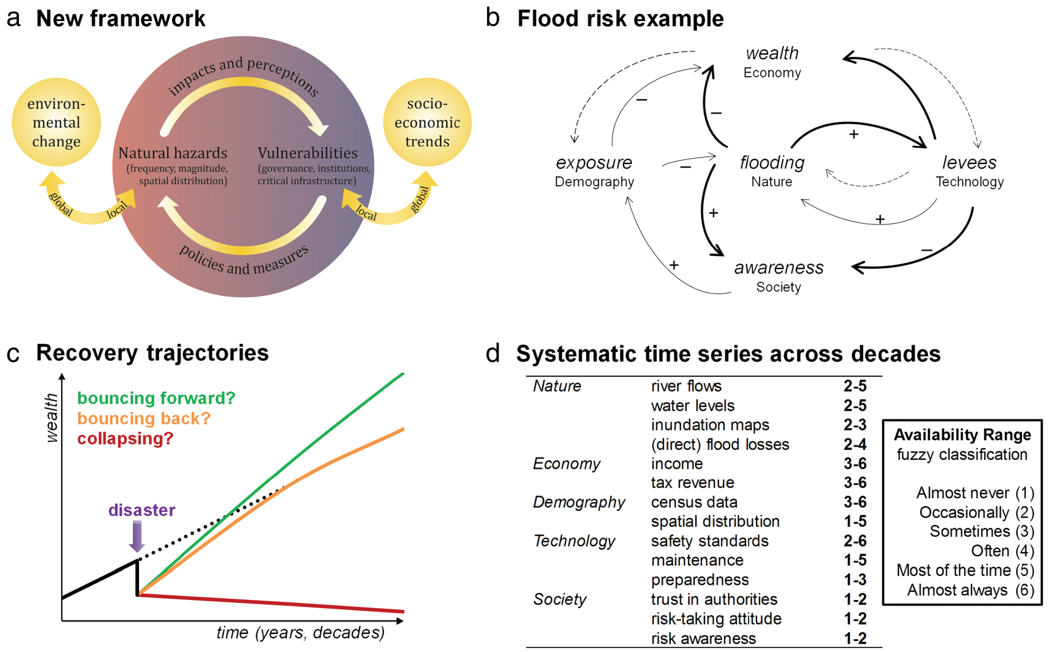

Figure 2. (a) Analytical framework focusing on the dynamics produced by the (local) interplay of natural hazards and vulnerabilities under (global) environmental change and socioeconomic trends. (b) Flood risk example at the local scale: explanatory model based on Di Baldassarre et al. (2013) emphasizing hypothetical feedbacks between five key variables that are assumed to influence each other and change gradually overtime (thin arrows), while being abruptly altered by the sudden occurrence of flooding (thick arrows). Dashed arrows indicate control mechanisms: wealth influences how flood exposure can potentially change overtime and also determines whether levees can be built or not, while levees reduce the frequency of flooding. (c) Hypothetical wealth trajectories in relation to disaster occurrences: bouncing back, forward or collapsing after a major disaster. (d) Ranges of availability of systematic time series across decades in the study of flood risk dynamics. The fuzzy classification highlights the limited availability of data to carry out empirical studies about socionatural interactions.

events can also gradually generate damage (Moftakhari et al., 2017), which erodes community resilience and sustains a negative spiral toward significant loss of social and economic capital, as seen for example in parts of Southern Africa (Rockström, 2003). The integrative framework can help specify competing hypotheses, alternative to the one depicted in Figure 2b, explaining why some communities learn from frequent and severe hazards while others do not.

4.2. Diminishing Returns and Unintended Consequences

Negative effects of risk reduction measures, such as the safe-development paradox, are explained by the model as a decrease of risk awareness produced by the prevention of frequent flooding caused by higher levees, which contributes to increasing exposure, and therefore higher losses (Figure 2b). This explanatory model also suggests the need of empirical studies about change in risk awareness across decades. Unfortunately, systematic monitoring of these variables, that is, longitudinal studies and comparable surveys of risk perception, is almost never available (Figure 2d).

4.3. Increase the Visibility of Prevention

Our framework can also provide guidance to identify, and systematically investigate, DRR bright spots emphasizing the social and natural factors that underlay different recovery trajectories (Figure 2c). After the occurrence of a major disaster, will the socionatural system bounce back or even forward? Or will it collapse? Viglione et al. (2014), for example, used an explanatory model similar to the one depicted in Figure 2b to uncover the socionatural conditions in which different trajectories are produced. The outcomes highlighted the major role of attitudes toward risk, trust in DRR authorities, and the capacity to maintain high levels of risk awareness.

To advance systematic empirical research, we propose the following essential steps. The integrative framework, which emphasizes the interplay of natural hazards and vulnerabilities (Figure 2a), can be used to derive one or more explanatory models (as alternative hypotheses) about the way in which social, technical, and natural variables influence each other (Figure 2b). These models can then be tested by evaluating their capability to capture emerging tendencies, such as adaptation dynamics or safe-development paradoxes, or used to explore the socionatural factors triggering different trajectories (Figure 2c). Lastly, these explanatory models can guide empirical studies as they can inform about the type of data we need to collect (Figure 2d) to better support evidence-based DRR. Empirical studies will in turn allow evaluating the explanatory power of alternative models. While the application example presented here is about flood risk, the framework can also specify the scope of enquiry and guide data collections for other natural hazards.

5. Future Directions and Priorities

Rethinking the foundations of DRR research brings significant analytical challenges. Our framework recognizes the importance of systematic monitoring across decades to get new insights about the temporal development and effectiveness of alternative actions. Valid outcome measures are urgently needed to assess DRR performance overtime and across contexts. Combining information about the interaction of social and natural systems opens new exciting avenues to assess whether and how diverse forms of community organization and behavior give rise to different outcomes.

Over the past decades, DRR research and practice has benefitted from exploiting systematic information about physical processes, population census, economic data, and disaster losses. Yet, to explore both unintended consequences and unexpected successes, we need to make better use of other sources of data to track feedback mechanisms between natural hazards and sociotechnical vulnerabilities overtime. Flood risk is merely one example where more systematic time series on risk perception, trust in authorities, awareness, and preparedness are urgently needed.

The proposed framework integrates the current paradigms to solve empirical puzzles in DRR, and provide guidance for empirical studies to unravel the nexus between physical, human, and technological systems. These are critical steps to generate deeper knowledge about the interplay between these interconnected systems, which is essential for making wise decisions about DRR.

Acknowledgments
The authors draw on discussions with fellows of the Centre of Natural Hazards and Disaster Science (CNDS), a strategic research center supported by the Swedish Government that brings together social, engineering and earth scientists involved in the study of DRR.

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