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SUNRAISE: Sustainable Natural Resource Use in Arctic and High Mountainous Areas

Report on:

Lecture Material

Risk, Vulnerability and Resilience: Concepts and Understanding

Partner number: P12

Jawaharlal Nehru University, New Delhi

India

Disclaimer

Risk, Vulnerability and Resilience: Concepts and Understanding

Semester -I: July – December

Coordinator	Prof P K Joshi
Credits	4 Credits
Lecturers	Prof P K Joshi
Level	M.A.
Host institution	Special Centre for Disaster Research (SCDR), Jawaharlal Nehru University, New Delhi
Course duration	One Semester [July - December] Started in July 2019

Summary

This one full semester core course provides the Master level students of Disaster Studies the basic understanding of the concept of risk, vulnerability, and resilience. This course focuses on the wide range of vulnerability and risk assessment processes and methods. This course is about procedures to collect, analyze and evaluate geospatial data for risk assessment from natural and man-made hazards. The course includes individual assignments.

Target Student Audiences

Semester - I Students of M.A.

Prerequisites

- Nil

Aims and Objectives

This course has been designed with a view to help students in developing a comprehensive understanding and knowledge on vulnerability assessment. The main objectives of the course are: (i) To help students understand the concepts of risk, vulnerability, resilience, and vulnerability assessment methods, critically analyze them, (ii) To understand the basics to develop framework and recommendation for vulnerability assessment techniques, (iii) To help students guide through entire process of risk assessment using geospatial domain, and (iv) To understand and formulate requirements of hazard data and methods.

General Learning Outcomes:

By the end of the course, successful students will:

- Understand the fundamental concept and science of vulnerability
- Learn the developments in approaches of vulnerability assessment
- Profound view about vulnerability of different systems
- Discriminate and interpret socioeconomic, cultural, and biophysical vulnerabilities ,
- Understand importance of geospatial approaches for vulnerability assessment

Overview of Sessions and Teaching Methods

The course will make most of interactive and self-reflective methods of teaching and learning including mainly lectures and presentations. It will start with an overview of vulnerability concepts and related terms. Subsequently it will build the science and practice of assessment methods and integration of geospatial approaches. The sessions will be take help of blended teaching and learning approaches for interaction lecturing on different course components.

Course Workload

The table below summarizes course workload distribution:

Activities	Learning outcomes	Assessment	Estimated workload (hours)
In-class activities			
Lectures and Presentations	Introduction to the concepts of Vulnerability. Key Terms and Definitions – Hazard, Vulnerability, Exposure, Coping Capacity and Resilience, Risk and related terms	Mid Semester Examination	04
Lectures and Presentations	Vulnerabilities of different systems (social and ecological), tipping points in the Earth System, issues for developing countries.	Mid Semester Examination	04
Lectures and Presentations	Basics of vulnerability and risk assessment (concept of exposure, sensitivity, and adaptive capacity), methods for analysis, decision analysis, management of uncertainty, and analysis of inherent and chronic vulnerabilities as well as those related to extreme events and hazards.	Mid Semester Examination	08
Lectures and Presentations	Development of framework for vulnerability assessment. Integration of social and natural science perspective and approaches to identify the purpose and focus of the vulnerability assessment (with the examples from different sectors). Qualitative to semi-quantitative methods to assess vulnerabilities to climate change.	Mid Semester Examination	08
Lectures and Presentations	Introducing disaster risk assessment and management, and rebuilding on importance of geospatial data. Elements at risk, classification, infrastructure, critical facilities, demography and collection of related information. Sources and methods of obtaining spatial data for risk assessment and presentation for various types of hazards. Hazard profiling, multiple hazard mapping, and maximum usage of Internet search and acquiring open and free (low cost) data. Participatory GIS, spatial multi-criteria evaluation and decision-making – to	End Semester Examination	08

	include component of vulnerability assessment (social, physical, ecological and other).		
Lectures and Presentations	Models for risk assessment and loss estimation. Qualitative and Quantitative risk assessment (including flood, seismic, landslide and technical risk assessment). Risk evaluation, cost benefit analysis and necessities for emergency planning and environmental impact assessment.	End Semester Examination	06
Lectures and Presentations	Spatial and holistic assessment of vulnerability (social, economic, environmental) to Natural Hazards (Case Studies) - Seismic Risk (Earthquakes and landslides) Floods, Heat waves, Drought, Forest fires, Coastal erosion	End Semester Examination	06
Independent work			
Individual Assignments	Ability to interpret data, and to use the concepts, tools, and methods for communicating information	Individual Presentations	12
Total			**56**

Grading

The students' performance will be based on the following:

- Quizzes/Surprise Test – 10%
- Mid Semester Examination – 30%
- End Semester Examination – 50%
- Individual Assignments – 10%

Course Schedule: **Semester -I: July – December (Proposed)**

Course Assignments

The Structure of Individual Assignments will be as follows:

- Book review on the given topic.
- Review of research articles and working paper with given objectives.

Literature

- Bankoff, G, Frerks G, and Hilhorst D, (2004). Mapping Vulnerability: Disasters, Development and People. eds. Pp. 115-127. London: Earthscan.
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- Preston, B. L., Yuen, E. J., & Westaway, R. M. (2011). Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. *Sustainability Science*, *6*(2), 177–202. https://doi.org/10.1007/s11625-011-0129-1
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- van Westen CJ, Alkema D, Damen MCJ, Kerle N, and Kingma NA (2011). Multi-hazard risk assessment. United Nations University – ITC School on Disaster Geoinformation Management (UNU-ITC DGIM).
- Zakour, M.J. and Gillespie, D.F. (2013). Community Disaster Vulnerability – Theory, Research and Practice. Springer New York Heidelberg Dordrecht London

Reading List Used

SET - I

1. Luna, F. 2018. Vulnerability. *Encyclopedia of the Anthropocene* 127-135.

2. Dominey-Howes, D. 2018. Hazards and disasters in the Anthropocene: some critical reflections for the future. *Geosceince Letters.* **5,** 7 (2018). https://doi.org/10.1186/s40562-018-0107-x

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18. Liu, Z., Nadim, F., Garcia-Aristizabal, A., Mignan, A., Fleming, K., Luna, B.Q. 2015. A three-level framework for multi-risk assessment, *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 9:2, 59-74.

SET – IV

19. Rao, T.N. Validation of Analytical Methods. IntechOpen.

20. Stallings, W.M., Gillmore, G.M. 1971. A note on ‘Accuracy’ and ‘Precision’. Journal of Educational Measurement 8(2), 127-129.

21. Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37, 35-46.

22. Manfré, L.A., Hirata, E., Silva, J.B., Shinohara, E.J., Giannotti, M.A., Larocca, A.P.C., Quintanilha, J.A. 2012. An Analysis of Geospatial Technologies for Risk and Natural Disaster Management. *ISPRS International Journal of Geo-Information* 1, 166-185.

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TERMS

P K Joshi

Vulnerability

- the quality or state of being exposed to the possibility of being attacked or harmed, either physically or emotionally.
- Latin *vulnerare* : to wound

Source: Dictionary.com

Vulnerability

- Sen (1981)
- Vulnerability to famine and food insecurity
  - Developed to explain vulnerability to famine in the absence of shortages of food or production failures.
  - Described vulnerability as a failure of entitlements and shortage of capabilities.

Vulnerability

- Vulnerability to hazards
  - Identification and prediction of vulnerable groups, critical regions through likelihood and consequence of hazard (Burton, et al., 1978; 1993)
- Human ecology
  - Structural analysis of underlying causes of vulnerability to natural hazards (Hewitt, 1983).
- Vulnerability to climate change and variability
  - Explaining present social, physical or ecological system vulnerability to (primarily) future risks, using wide range of methods and research traditions (Klein and Nicholls, 1999).

Hazard

- A danger or risk
- Chance; probability
  - Turkish (zar)
  - Arabic (azzahr)
  - Spanish (azar)
  - Old French (hasard)
- the threat potential posed to man or nature by events originating in, or transmitted by, the natural or built environment (Kates, 1978)

Hazard

- The term ‘hazard’ is used in many contexts.
- Community context
  - references are made to meteors, earthquakes and floods as ‘natural hazards,
- Google
  - >7 million hits
  - some of these present ‘hazard’ as synonymous with ‘risk,’
  - While others adopt the more common ‘source of harm’ usage.

Hazard

ENERGY SOURCES	ORIGIN	EFFECTS	STATUS/MODES
• Biological	• Nature	• Health	• Dormant
• Chemical	• Anthropogenic	• Safety	• Armed
• Ergonomic	• Technological	• Economic	• Active
• Mechanical	• Sociological	• Environmental	
• Physical	• Environmental		
• Psychosocial			

Hazard

- Sources of potentially damaging energy which either exist naturally or as a result of humankind's modification of the naturally occurring world……where damage (injury) is the result of an incident energy whose intensity at the point of contact with the recipient exceed the damage threshold of the recipient (Viner, 1991).

Exposure

- make (something) visible by uncovering it.
- the state of having no protection from something harmful.

- Occupational Health and Safety (OHS)

Risk

- a situation involving exposure to danger expose (someone or something valued) to danger, harm, or loss.
  - Italian (risco or rischiare)
  - French (risque, reisquer)
- A probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal vulnerabilities, and that may be avoided through preemptive action.

Disaster

- A sudden accident or a natural catastrophe that causes great damage or loss of life.
  - Latin (astrum)
  - Italian (dis-astro)

Disaster

- A disaster is an occurrence disrupting the normal conditions of existence and causing a level of suffering that exceeds the capacity of adjustment of the affected community.
- Major Disaster (Sheehan and Hewitt, 1969)
  - At least 100 people dead,
  - at least 100 people injured, or
  - at least $1 million damage

Tipping point

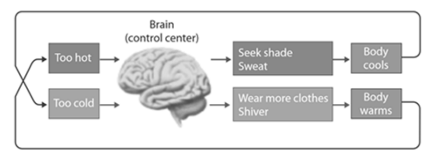
- the point at which a series of small changes or incidents becomes significant enough to cause a larger, more important change (= point of no return).
- "adaptation tipping point"
  - "the threshold value or specific boundary condition where ecological, technical, economic, spatial or socially acceptable limits are exceeded

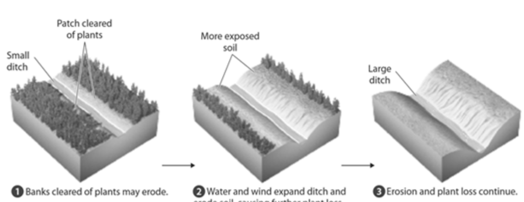
Feedback System

- Because energy flows freely into and out of systems, all systems respond to inputs and, as a result, have outputs
- A special kind of response, **feedback**, occurs when the output of the system also serves as an input

Feedback System

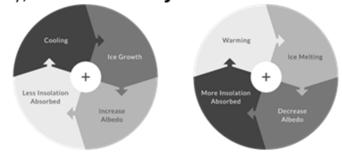
- If a path of successive connections can be traced from any given component back to itself, a closed or 'feedback' loop is formed
  - An even number (including zero) of negatively correlated connections counted around the loop gives a **positive feedback**, which will act to amplify an initial perturbation in the state of any component within this loop.
  - Conversely, an odd number of negative correlations a **negative feedback**, which will tend to dampen any perturbation, thus stabilizing the system.





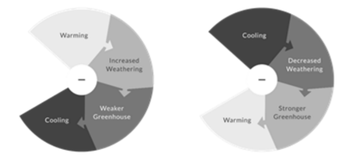
+ive Feedback System

- with a positive correlation (i.e., an increase in the state of one component causes an increase in a second, or, a decrease in the state of one component causes a decrease in a second); ***Ice –Albedo feedback***



-ive Feedback System

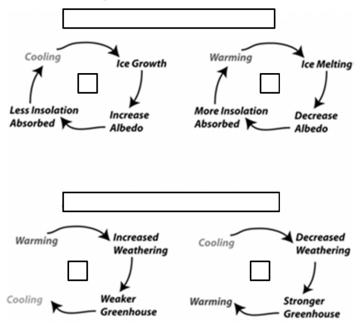
- with a negative correlation (i.e., an increase in the state of one component causes a decrease in a second, or vice versa); ***Weathering feedback***



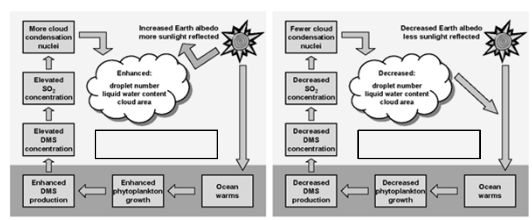
Feedback System

- *Negative feedback*: the system's response is in the opposite direction of initial input
  - Often self-limiting or self-regulating
- *Positive feedback*: an increase in output leads to a further increase in output
  - Vicious cycle
  - Destabilizing

Yin and Yang



Claw Hypothesis

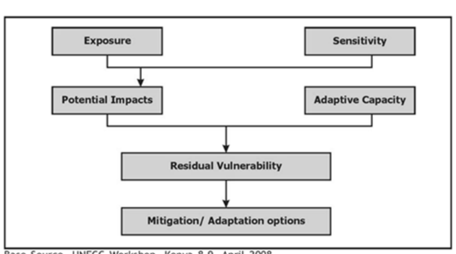


CLAW hypothesis - Robert J **C**harlson, James **L**ovelock, Meinrat **A**ndreae & Stephen G. **W**arren

Vulnerability Frameworks

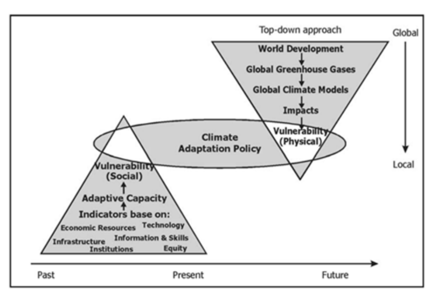
Vulnerability = Risk (Hazard x Exposure)

± Adaptation (Responses/Options) or Sensitivity

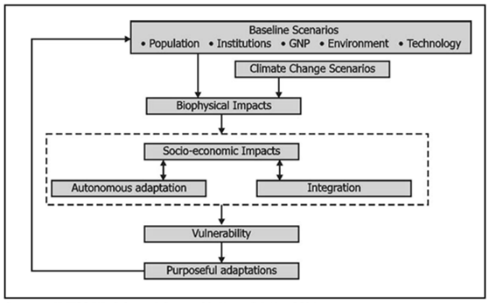


Base Source -UNFCC Workshop, Kenya 8-9, April 2008

Top-down vs. Bottom-up

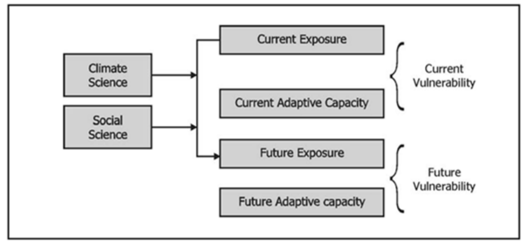


Top-down approach



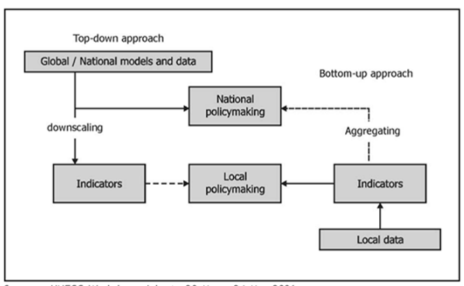
Source : UNFCC Workshop, Jakarta, 20 Mar - 24 Mar 2006

Bottom-up approach



Source: UNFCC Compendium Presented at Manila April

Integration of approaches

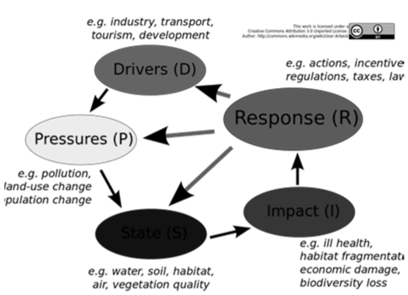


Source : UNFCC Workshop, Jakarta 20 Mar - 24 Mar 2006

Vulnerability Frameworks

Characteristics of assessment	Current Vulnerability	Future Vulnerability
Origin of the danger	Natural variability	Human influence
Risk reduction objective	Internal vulnerability	Internal and external vulnerability
Development components	Social and economic	Social, economic and environmental
Goal of the analysis	Normative, reactive	Normative, proactive
Reasons of interventions	Voluntary assistance	Obligatory assistance
Time scale	Discrete and short-term	Gradual and long-term
Spatial scale	Local-regional	Regional-global
Level of uncertainty	Low to medium	Medium to high
Type of dangers	Known dangers	New and known dangers
View of the system	Static an reactive	Dynamic and adaptive
Adaptation focus	Emergencies	Trends and Emergencies

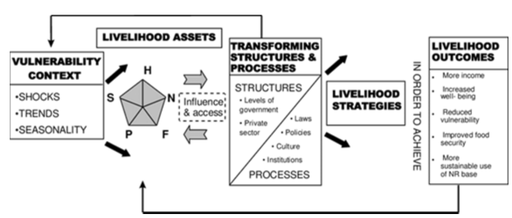
DPSIR



DIFID

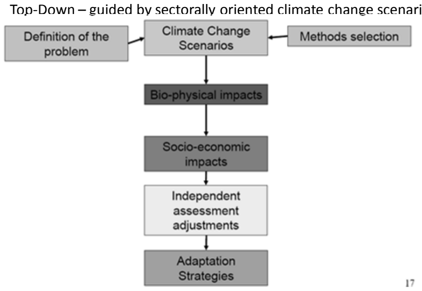
Department for International Development

- The livelihoods model



IPCC Framework

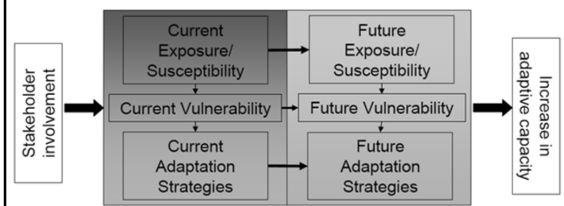
- Top-Down – guided by sectorally oriented climate change scenarios



APF/UNDP-GEF

Adaptation Policy Framework

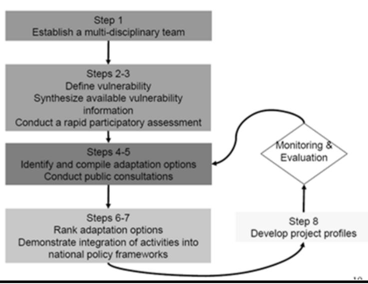
- Bottom-Up –with vulnerability as the entry point and a transversal orientation



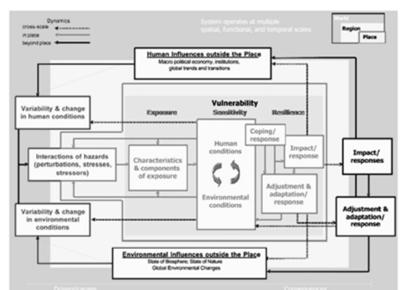
NAPA approach

National Adaptation Programmes of Action

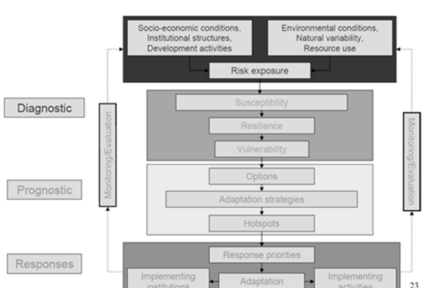
- Bottom-Up –where vulnerability is the entry point and enhancing endogenous adaptive capacity is sought



Multi-scale analysis



Multi-scale analysis



Source: Winograd, 2004

Agriculture communities

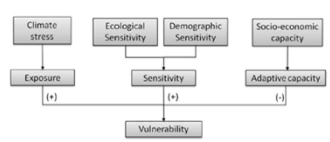
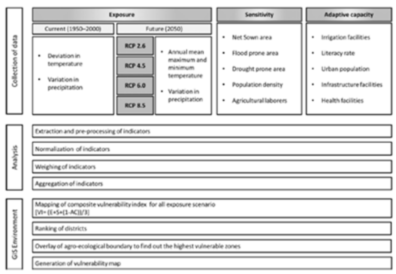
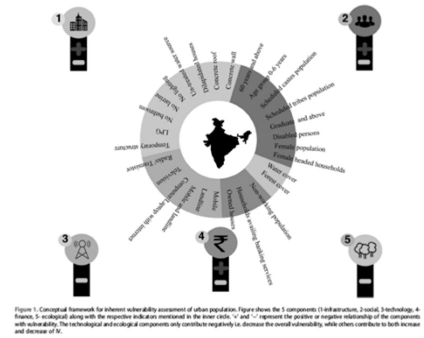


Fig. 1 Conceptual framework for assessment of vulnerability

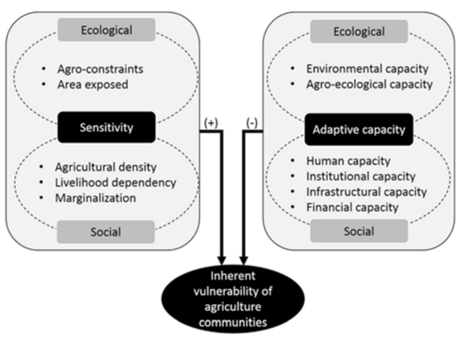
Agriculture communities



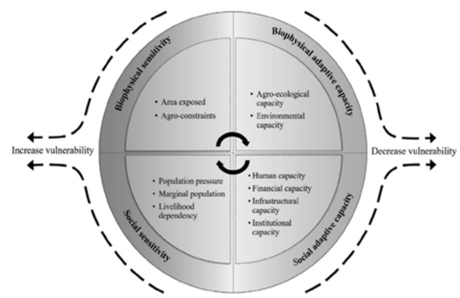
Urban communities



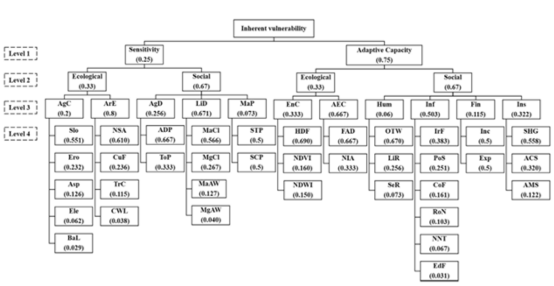
Mountain Agriculture communities



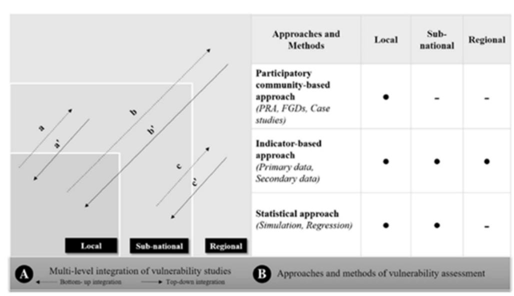
Mountain Agriculture communities



Mountain Agriculture communities



Vulnerability assessments



Terms

- **Exposure** (i.e. *elements potentially at risk*) - It represents the presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social or cultural assets in places that could be adversely affected.
- **Vulnerability** - It represents the *propensity* or *predisposition* of a community, system, or asset to be adversely affected by a certain hazard. In a broad sense it should include economic, social, geographic, demographic, cultural, institutional, governance and environmental factors

Terms

- **Hazard** - It represents the *physical phenomenon* (e.g. sea level rise, storm surges) that has the *potential to cause damage and loss* to property, infrastructure, livelihoods, service provision and environmental resources.
- **Risk** - It quantifies and classifies *potential consequences of a hazard events* on the investigated areas and receptors (i.e. elements potentially at risk) combining hazard, exposure and vulnerability. It is expressed in *probabilistic or relative/semi-quantitative terms*.

Terms

- **Multi-hazard** = It refers to - different hazardous events threatening the same exposed elements (with or without temporal coincidence); - hazardous events occurring at the same time or shortly following each other (cascade effects)
- **Multi-risk** = It determines the whole risk from several hazards, taking into account possible hazards and vulnerability interactions entailing both a multi-hazard and multi-vulnerability perspective.

  It is related to multiple risks such as economic, ecological, social, etc

Risk

- the probability of loss caused by the interactions between the vulnerability of exposure and the hazard (ISDR, 2004)

= Hazard×Vulnerability×Exposure

- the magnitude of impact resulting from realization of the hazard

= Probability×Consequence

Author	Year	Definition	Expression
Fournier	1979	the possibility of a loss	$\text{Risk} = \text{Value} \times \text{Vulnerability} \times \text{Hazard}$
Blaikie et al.	1994	a compound function of hazard and vulnerability of exposure to that specific hazard	$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$
Smith	1996	the possibility of a loss caused by disaster	$\text{Risk} = \frac{\text{Probability} \times \text{Loss}}{\text{Loss mitigation}}$
IUGS	1997	the probability of occurrence and the severity may cause toward human life, property and the environment	$\text{Risk} = \text{Probability} \times \text{Consequence}$
Tobin and Montz	1997	expected loss caused by disaster and the probability of the loss happened	$\text{Risk} = \text{Probability} \times \text{Consequence}$
Hurst	1998	the probability of occurrence and excepted loss	$\text{Risk} = \text{Probability} \times \text{Consequence}$
Alexander	2000	"the likelihood, or more formally the probability, that a particular level of loss will be sustained by a given series of elements as a result of a given level of hazard"	$\text{Total Risk} = (\Sigma\text{elements at risk}) \times \text{Hazard} \times \text{Vulnerability}$
Hahn et al.	2003	represented by hazard, vulnerability, exposure and coping capacities	$\text{Risk} = \text{Hazard} + \text{Exposure} + \text{Vulnerability} - \text{Coping Capacities}$
ISDR	2004	"The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural hazards and vulnerable conditions"	$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}$
Dilley et al.	2005	the combination of three components: hazard, exposure, and vulnerability.	$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}$

Terms

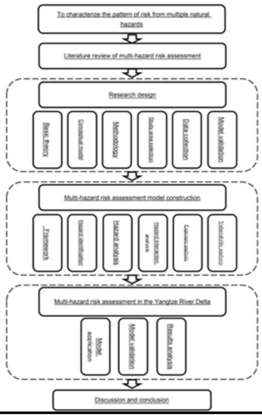
- **Multi-vulnerability** - refers to a variety of exposed sensitive targets (e.g. population, infrastructure, cultural heritage, etc.) with possible different vulnerability degree against the various hazards;

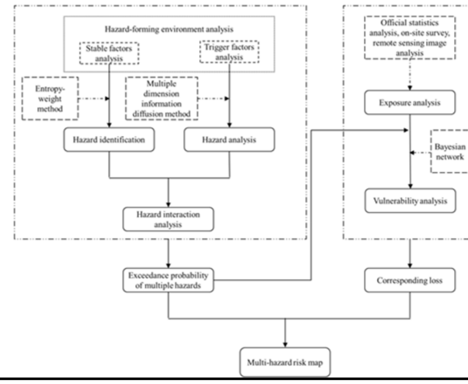
  - time-dependent vulnerabilities, in which the vulnerability of a specific class of exposed elements may change with time as consequence of different factors (e.g. the occurrence of other hazardous events).

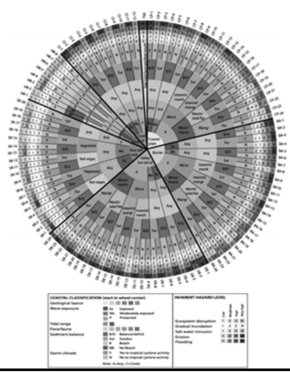
SHORELINE EROSION 1.1	*NO INTERACTION* 1.2	A narrow steep beach without berms is open to wave attack 1.3	Coastal retreat contributes to the decrease in strength 1.4
Flooding can cause extensive coastline retreat close to the river mouth or inlet 2.1	**RIVERINE FLOODING** 2.2	The concurrence of large waves breaking and flooding along the same coast increases destabilization 2.3	Breaches or overwash related to flooding induce landslides 2.4
A large fetch and/or a wide coastal sector exposure to the prevailing wind determines the highest rate of erosion 3.1	The contemporary occurrence of flooding and large waves breaking on the same coast increase destabilization along it. 3.2	**SURGES** 3.3	Surges can affect a high cliff, both eroding the base (wave-cut notch) and scattering the marine spray along the slope 3.4
The occurrence of landslides, associated to the quick removal of the talus, can accelerate the rate of cliff recession 4.1	Landslides and related phenomena can contribute to cut off or divert a flow in a water course 4.2	*NO INTERACTION* 4.3	**LANDSLIDES** 4.4

dePippo et al. (2008)

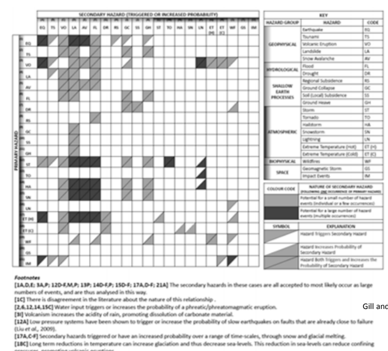
Framework



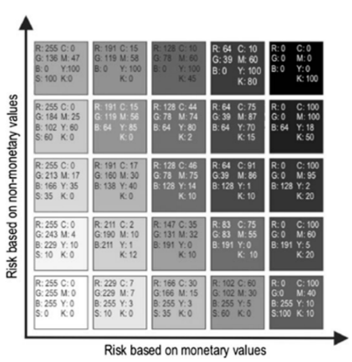




Appelquist and Balstrøm, 2014

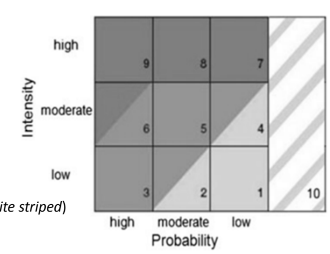


Gill and Malamud, 2014



Swiss Matrix

High hazard (*red zone*)
Medium hazard (*blue zone*)
Low hazard (*yellow zone*)
Residual hazard (*yellow white striped*)



Kunz and Hurni (2008)

Chapter 1

Conceptual Frameworks of Vulnerability Assessments for Natural Disasters Reduction

Roxana L. Ciurean, Dagmar Schröter and
Thomas Glade

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/55538

1. Introduction

The last few decades have demonstrated an increased concern for the occurrence of natural disasters and their consequences for leaders and organizations around the world. The EM-DAT International Disaster Database [1] statistics show that, in the last century, the mortality risk associated with major weather-related hazards has declined globally, but there has been a rapid increase in the exposure of economic assets to natural hazards.

Looking into more detail, UNISDR's Global Assessment Report 2011 (GAR11) [2] indicates that disasters in 2011 set a new record of $366 billion for economic losses, including $210 billion as a result of the Great East Japan Earthquake and the accompanying tsunami alone, and $40 billion as a result of the floods in Thailand. There were 29,782 deaths linked to 302 major disaster events including 19,846 deaths in the March earthquake/tsunami in Japan (figures presented by other disaster databases for 2011 summary e.g. NATCAT Service – MunichRE, are slightly different but in general agreement). Disaster databases, such as the ones referred to above, represent key resources for actors involved in policy and practice related with disaster risk reduction and response. However, considering their diversity and recognizing their different roles, one can identify at least one limitation in their use i.e. the inclusion criteria which inherently results in many hazard events not being registered. Compiling and analyzing an extensive natural disaster data set for the period 1993 – 2002, Alexander [3] showed that, for example, in the Philippines in 1996 there were 31 major floods, 29 earthquakes, 10 typhoons and 7 tornadoes. Due to population pressure, large areas of Luzon and other islands were denuded of their dense vegetation cover resulting in landslide prone slopes. Twelve major episodes of slope failure causing high damages to infrastructure and build up areas were registered in the archipelago during 1996. Although documentation of the Government expenditures to finance relief efforts for natural disasters during the 1996 – 2002 period is not completely contained in Figure 1 [4], one can observe that 1996 stands out as a particular year with high costs of rehabilitation.

Experience has shown that considering the frequency of disasters affecting the Philippines, its socio-economic context, and risk culture, the disaster management system tends to rely on a response approach. However, studies indicate that efforts are being made to engage more proactive approaches, involving mitigation and preparedness strategies [4]. In order to achieve this it is thus important to investigate not only the nature of the threat but also the underlying characteristics of the environment and society that makes them susceptible to damage and losses – in other words, the role of *vulnerability* in determining natural hazard risk levels.

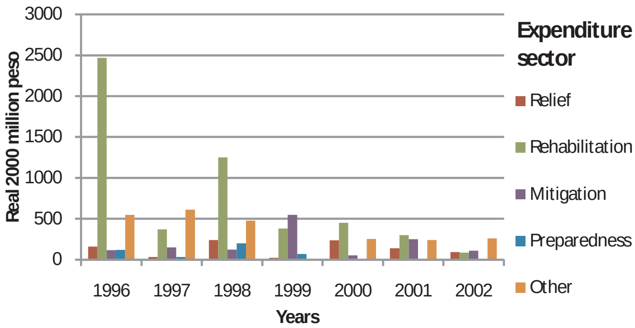


Figure 1. Philippines – annual expenditure under the National Calamity Fund (1996 – 2002) (Based on GDP at price market) [4]

BOX 1: Vulnerability – One term many meanings

In everyday use of language, the term vulnerability refers to the inability to withstand the effects of a hostile environment. The definition of vulnerability for the purpose of scientific assessment depends on the purpose of the study – is it to get a differential picture of global change threats to human well-being in different world regions? Is it to inform particular stakeholders about adaptation options to a potential future development? Is it to show that likelihood of harm and cost of harm have changed for a specific element of interest within the human-environment system? In scientific assessment the term vulnerability can have many meanings, differentiated mostly by (a) the vulnerable entity studied, (b) the stakeholders of the study.

The design of scientific assessment (as opposed to scientific research) has to respond to the scientific needs of the particular stakeholder who might use it [5]. An integral part of vulnerability assessment therefore is the collaboration with its stakeholders [6], [7]. Thus, the specific definition and the method of vulnerability assessment is specific to each study and needs to be made transparent in the specific context. An example set of definitions on vulnerability used in natural hazards risk assessment and global change research is presented in section 2.2, Table 1.

The objective of this work is to discuss and illustrate different approaches used in vulnerability assessment for hydro-meteorological hazards (i.e. landslides and floods, incl. flash floods) taking into account two perspectives: hazard vulnerability and global change vulnerability, which are rooted in the technical and environmental as well as social disciplines. The study is based on a review of recent research findings in global change and natural hazards risk management. The overall aim is to identify current gaps that can guide the development of future perspectives for vulnerability analysis to hydro-meteorological hazards. Following the introduction (section 1), the second section starts with a definition of vulnerability within the context of risk management to natural hazards (sub-section 2.1). Subsequently, various conceptual models (sub-section 2.2) and vulnerability assessment methodologies (sub-section 2.3) are analyzed and compared based on their different disciplinary foci. In the third section, the importance of addressing uncertainty in vulnerability analysis is discussed and lastly general observations and concluding remarks are presented.

2. Conceptual frameworks

2.1. Vulnerability and risk management to natural hazards

According to the UN International Strategy for Disaster Reduction (UNISDR) Report [8], there are two essential elements in the formulation of risk (Eq. 1): a potential event – hazard, and the degree of susceptibility of the elements exposed to that source – vulnerability.

$$\text{RISK} = \text{HAZARD X VULNERABILITY} \tag{1}$$

In UNISDR terminology on Disaster Risk Reduction [9], «risk» is defined as the combination of the probability of an event and its negative consequences". A «hazard» is "a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage".

Within the risk management framework, vulnerability pertains to consequence analysis. It generally defines the potential for loss to the elements at risk caused by the occurrence of a hazard, and depends on multiple aspects arising from physical, social, economic, and environmental factors, which are interacting in space and time. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management.

BOX 2: Risk management frameworks are generally designed to answer the following questions [10]:

What are the probable dangers and their magnitude? (*Danger Identification*)

How often do the dangers of a given magnitude occur? (*Hazard Assessment*)

What are the elements at risk? (*Elements at Risk Identification*)

What is the possible damage to the elements at risk? (*Vulnerability Assessment*)

What is the probability of damage? (*Risk Estimation*)

What is the significance of the estimated risk? (*Risk Evaluation*)

What should be done? (*Risk Management*)

2.2. Vulnerability models

There are multiple definitions, concepts and methods to systematize vulnerability denoting the plurality of views and meanings attached to this term. Birkmann [11] noted that 'we are still dealing with a paradox: we aim to measure vulnerability, yet we cannot define it precisely'. However, there are generally two perspectives in which vulnerability can be viewed and which are closely linked with the evolution of the concept [12]: (1) the amount of damage caused to a system by a particular hazard (technical or engineering sciences oriented perspective – dominating the disaster risk perception in the 1970s), and (2) a state that exists within a system before it encounters a hazard (social sciences oriented perspective – an alternative paradigm which uses vulnerability as a starting point for risk reduction since the 1980s). The former emphasizes 'assessments of hazards and their impacts, in which the role of human systems in mediating the outcomes of hazard events is downplayed or neglected'. The latter puts the human system on the central stage and focuses on determining the coping capacity of the society, the ability to resist, respond and recover from the impact of a natural hazard [13]. While the technical sciences perspective of vulnerability focuses primarily on physical aspects [14], the social sciences perspective takes into account various factors and parameters that influence vulnerability, such as physical, economic, social, environmental, and institutional characteristics [8]. Other approaches emphasize the need to account for additional global factors, such as globalization and climate change. Thus, the broader vulnerability assessment is in scope, the more interdisciplinary it becomes.

The different definitions of vulnerability can also be viewed from a functional and subject/object-oriented perspective i.e. considering the end-user of the scientific assessment results (e.g. technical boards, administration officers, representatives from the civil protection, international organizations, etc.) and the vulnerable entity (e.g. critical infrastructure, elderly population, communication networks, mountain ecosystems, etc.).

Working definitions(s): Vulnerability is…	Source
The degree of loss to a given element at risk or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)	[14]
The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards	[8]
The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from impacts of a hazard	[13]
The intrinsic and dynamic feature of an element at risk that determines the expected damage/ harm resulting from a given hazardous event and is often even affected by the harmful event itself. Vulnerability changes continuously over time and is driven by physical, social, economic and environmental factors	[11]
The degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change	[15], [16]

Table 1. General definitions of vulnerability used in risk assessment due to natural hazards and climate change

Vogel and O'Brien [17] emphasize that vulnerability is: *(a) multi-dimensional and differential* (varies for different dimensions of a single element or group of elements and from a physical context to another); *(b) scale dependent* (with regard to the unit of analysis e.g. individual, local, regional, national etc.) *and (c) dynamic* (the characteristics that influence vulnerability are continuously changing in time and space). With regards to the first characteristic, there are generally five components (or dimensions) that need to be investigated in vulnerability assessment: (1) the physical/functional dimension (relates to the predisposition of a structure, infrastructure or service to be damaged due to the occurrence of a harmful event associated with a specific hazard); (2) the economic dimension (relates to the economic stability of a region endangered by a a loss of production, decrease of income or consumption of goods due to the occurrence of a hazard); (3) the social dimension (relates with the presence of human beings, individuals or communities, and their capacities to cope with, resist and recover from impacts of hazards); (4) the environmental dimension (refers to the interrelation between different ecosystems and their ability to cope with and recover from impacts of hazards and to tolerate stressors over time and space); (5) the political/institutional dimension (refers to those political or institutional actions e.g. livelihood diversification, risk mitigation strategies, regulation control, etc., or characteristics that determine differential coping capacities and exposure to hazards and associated impacts).

During the last decades, various schools of thinking proposed different conceptual models with the final aim of developing methods for measuring vulnerability. The following sub-sections give a short overview of some of the conceptual models presented in [11], such as the double structure of vulnerability, vulnerability within the context of hazard and risk, vulnerability in the context of global environmental change community, the Presure and Release Model and a holistic approach to risk and vulnerability assessment. Other models not discussed herein are: The Sustainable Livelihood Framework, the UNISDR framework for disaster risk reduction, the 'onion framework', and the 'BBC conceptual framework', the last two developed by UNU-EHS (UN University, Institute for Environment and Human Security).

2.2.1. The double structure of vulnerability

According to Bohle [18] vulnerability can be seen as having an external and internal side (Figure 2). The *external* side is related to the exposure to risks and shocks and is influenced by Political Economy Approaches (e.g. social inequities, disproportionate division of assets), Human Ecology Perspectives (population dynamics and environmental management capacities) and the Entitlement Theory (relates vulnerability to the incapacity of people to obtain or manage assets via legitimate economic means). The *internal* side is called coping and relates to the capacity to anticipate, cope with, resist and recover from the impact of a hazard and is influenced by the Crisis and Conflict Theory (control of assets and resources, capacities to manage crisis situations and resolve conflicts), Action Theory Approaches (how people act and react freely as a result of social, economic or governmental constrains) and Model of Access to Assets (mitigation of vulnerability through access to assets). The conceptual framework of the double structure indicates that vulnerability cannot adequately be considered without taking into account coping[1] and response capacity[2].

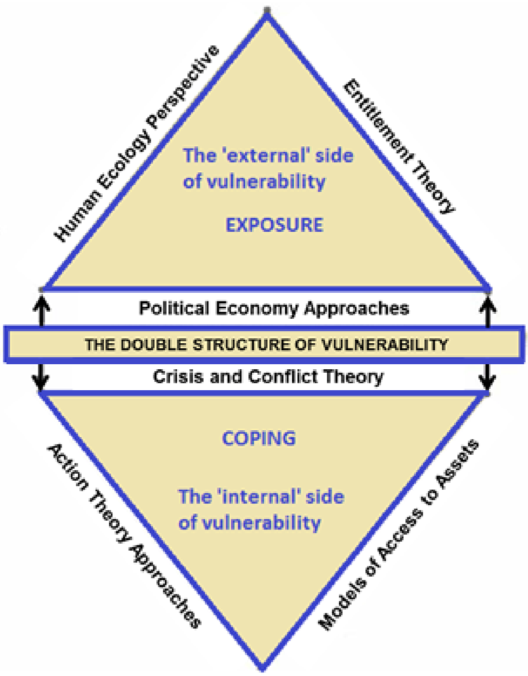


Figure 2. Bohle's conceptual framework for vulnerability analysis [18] in [11]

1 Coping capacity is the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters [8]

2 Capacity is the combination of all the strengths attributes and resources available within a community, society or organization that can be used to achieve agreed goals [8]

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2.2.2. Vulnerability within the framework of hazard and risk

The disaster risk community defines vulnerability as a component within the context of hazard and risk. This school usually views vulnerability, coping capacity and exposure as separate features. One example within this approach is Davidson's [19] conceptual framework, adopted in [20] and illustrated in Figure 3. This framework views risk as the sum of hazard, exposure[3], vulnerability and capacity measures. Hazard is characterized by probability and severity, exposure is characterized by structure, population and economy, while vulnerability has a physical, social, economic and environmental dimension. Capacity and measures are related with physical planning, management as well as social – and economic capacity.

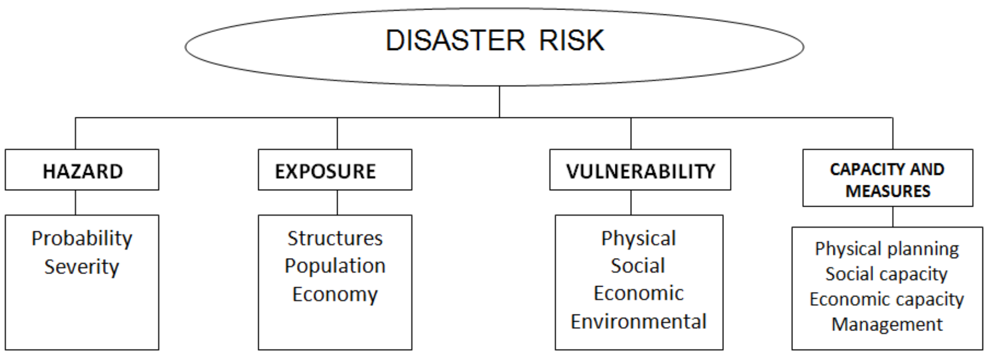

Figure 3. Conceptual framework to identify risk [20] in [11]

2.2.3. Vulnerability in the global environmental change community

Turner [21] developed a conceptual framework considered representative for the global environmental change community primarily due to its focus on the coupled human-environment systems. Their definition of vulnerability encompasses exposure, sensitivity and resilience. Exposure contains a set of components (i.e. threatened elements: individuals, households, states, ecosystem, etc.) subjected to damage and characteristics of the threat (frequency, magnitude, duration). The sensitivity is determined by the human (social capital and endowments) and environmental (natural capital or biophysical endowments) conditions of the system which influence its resilience[4]. The last component is enhanced through adjustments and adaptation.

A system's vulnerability to hazards consists of (Figure 4) (i) linkages to the broader human and biophysical (environmental) conditions and processes operating on the coupled system in

3 Exposure is defined as the totality of people, property, systems or other elements present in hazard zones that are thereby subject to potential losses [8]

4 Resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions [8]

question; (ii) perturbations and stressors/stresses[5] that emerge from this conditions and processes; and (iii) the coupled human – environment system of concern in which vulnerability resides, including exposure and responses (i.e. coping, impacts, adjustments, and adaptation) [21].

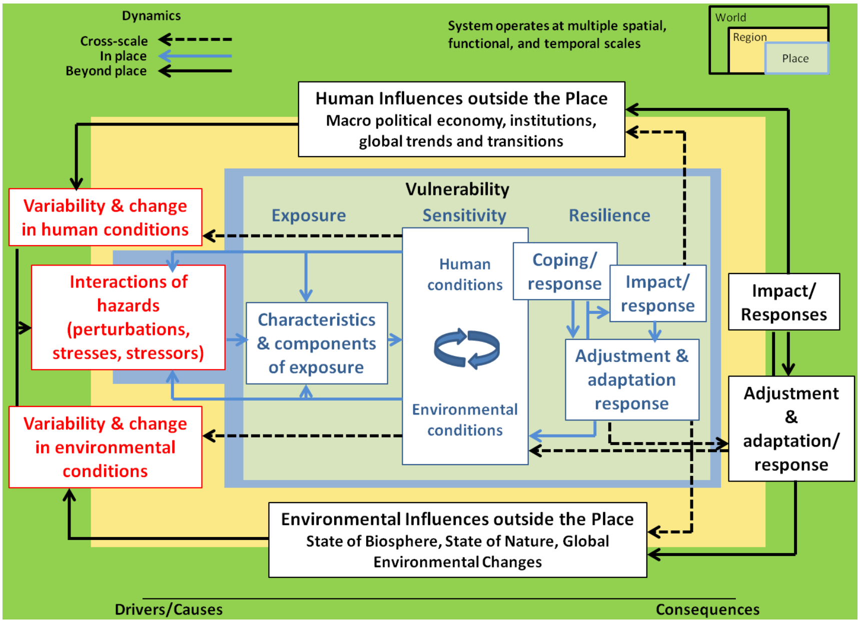

Figure 4. Vulnerability conceptual framework [21] in [11]

2.2.4. The Pressure and Release model (PAR model)

The model operates at different spatial (place, region, world), functional and temporal scales and takes into account the interaction of the multiple perturbations and stressor/stresses [22]. Hazards are regarded as being influenced from inside and outside of the analyzed system; however, due to their character they are commonly considered site-specific. Thus, given their complexity, hazards are located within and beyond the place of assessment. The Pressure and Release model (PAR model) is based on the commonly used equation which defines risk as a function of the hazard and vulnerability (Eq. 1). It emphasizes the underlying driving forces of vulnerability and the conditions existent in a system that contribute to disaster situations when a hazard occurs. Vulnerability is associated with these conditions at three progressive levels: (1) *Root causes*, which can be, for example, limited access to power, structures or resources; or related with political ideologies or economic systems; (2) *dynamic pressures* represented, for example, by demographic or social changes in time and space (e.g. rapid population decrease, rapid

5 Stress is a continuous or slowly increasing pressure, commonly within the range of normal variability. Stress often originates and stressors (the sources of stress) often reside within the system [21]

urbanization, lack of local institutions, appropriate skills or training); and (3) *unsafe conditions* posed by the physical environment (e.g. unprotected buildings and infrastructure, dangerous slopes) or socio-economic context (e.g. lack of local institutions, prevalence of endemic diseases). In Birkmann's opinion [11], this conceptual framework is an important approach which goes beyond identification of vulnerability towards addressing its root causes and driving forces embedded in the human-environment system.

2.2.5. A holistic approach to risk and vulnerability

In this approach vulnerability is conditions by three categories of factors [23]:

- Physical exposure and susceptibility – regarded as hazard dependent
- Fragility of the socio-economic system – non hazard dependent
- Lack of resilience to cope and recover – non hazard dependent

The authors emphasize the importance of measuring vulnerability from a comprehensive and multidisciplinary perspective. The model (Figure 5) takes into account the consequences of direct physical impacts (exposure and susceptibility) as well as indirect consequences (socio-economic fragility and lack of resilience) of potential hazardous event. Within each category, the vulnerability factors are described with sets of indicators or indices. The model includes a control system which alters indirectly the level of risk through corrective and prospective interventions (risk identification, risk reduction, disaster management).

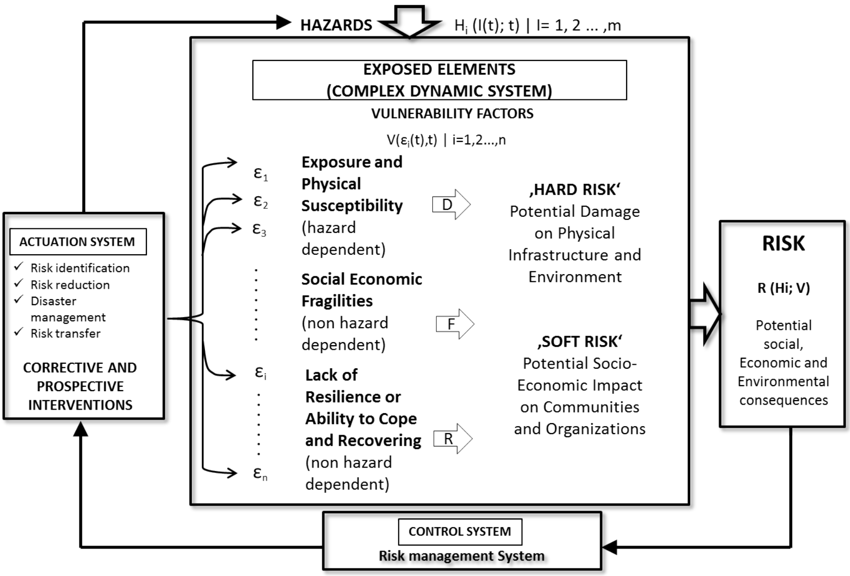

Figure 5. Conceptual framework for holistic approach to disaster risk assessment and management [23] in [11]

The conceptual frameworks described above are different in scope and thematic focus. The vulnerability definition encompasses exposure, coping capacities, sensitivity and adaptation responses in the model of double structure of vulnerability [18] and the global environmental change school model [21], while within the framework of hazard and risk, vulnerability is separated from these characteristics. The holistic approach and the PAR Model indicate factors and conditions of vulnerability able to measure direct physical impacts as well as indirect consequences of disasters. It is obvious that different vulnerability frameworks serve for different disciplinary groups and consequently there is no generally applicable model that can satisfy all specific needs. While our ability to understand vulnerability is enhanced by these conceptual models, only some of them result in paradigms of quantitative or qualitative vulnerability assessment. An illustration of the methods used in physical and social vulnerability evaluation is presented below.

2.3. Vulnerability assessment methods

In the last decades, methods of vulnerability assessment have been developed and tested within the framework of risk analysis, most of them designed for a specific hazard. Research has demonstrated that irrespective of the type of assessment (natural - or social science based), there are some key issues related with the definition of the vulnerable system that must be addressed. Of particular importance is to establish the objective and (time/space) scale of analysis. This will dictate the type of approach (method) employed taking into account data and resource availability. The most detailed vulnerability assessments are conducted at local level, often of individuals or households, but the data required at this level is not readily available. For decisional purposes, regional or national-level assessment can be employed, resulting though in inherent loss of information. An additional issue is the problem of down or up-scaling which implies different levels of generalization and assumption making. This is particularly important when the quality and quantity of data is low because it influences greatly the certainty of the outcome.

Vulnerability is not only site-specific and scale dependent but also varies for different types of hazards (e.g. floods, landslides, earthquakes, tsunamis), due to process characteristics (e.g. generation mode, rate of onset, intensity, area affected, temporal persistence in the environment, etc.) and type of element (or set of elements) at risk. Consequently, the methods used for the evaluation of earthquake vulnerability are not directly transferable to droughts, for example. Vulnerability of exposed objects or systems may vary also for similar processes ([24], [25]). Furthermore, it is acknowledged ([3], [24], [26]) that various types of the same process (e.g. debris flow vs. rock falls for landslide processes, fluvial floods vs. pluvial floods for flood processes) can result in different damage patterns.

An additional factor that must be considered in vulnerability assessment is the target of analysis i.e. the elements at risk. In general terms, these are the objects or systems which pose the potential to be adversely affected [27] by a hazardous event. In [28] the elements at risk are defined as the objects, population, activities and processes that may be differently affected by hazardous phenomena, in a particular area, either directly or indirectly.

Damages or losses caused by the occurrence of hazards can be manifold. In short term, when a disaster strikes, the primary concern are the potential losses due to casualties (fatalities, injuries and missing persons), physical (functional) consequences on services, buildings and infrastructure and direct economic loss. In long term, indirect economic consequences, social ‘disturbance’ and environmental degradation may become of greater importance. Many consequences cannot be measured or quantified easily. These are referred to as intangible losses (e.g. loss of social cohesion due to disruption of community, loss of reputation, psychological consequences resulting from disaster impacts, cultural effects, etc.). In vulnerability assessment, tangible losses (which can be measured, quantified) are mostly evaluated whereas intangible losses are at best described. The difference between the two types of losses makes their aggregation in a comprehensive consequence analysis very challenging.

In general vulnerability can be measured either on a metric scale, e.g. in terms of a given currency, or a non-numerical scale, based on social values or perceptions and evaluations [24]. Direct human-social and physical losses can be described and quantified using different methodological approaches. A non-exhaustive description of frequently used methods for physical and social vulnerability assessment is given below.

2.3.1. Social vulnerability assessment

The concept of social vulnerability is complex. A number of studies developed within research projects specifically dedicated to measuring social vulnerability to natural hazards (for example, see [29]) showed that there are fundamental differences between the main types of assessment approaches. These are largely based on qualitative or quantitative research traditions which have important differences in their related paradigms.

There are two distinct perspectives on the social dimension in vulnerability assessment: (1) one refers to *intangible losses* and the related elements at risk whose value cannot be easily counted or valued in economic terms. Such factors may be categorized, for example (but are not limited to) in environmental (biodiversity, natural scenery/tourist attractions, environmental assets used in economic activity, etc.), cultural (structures, historical material, sites of particular cultural value/importance, etc.), institutional (loss of both human and material resources related to the functioning of public institutions including health, law enforcement, education and maintenance). Another interpretation refers to (2) *the underlying socio-economic factors in a society causing or producing vulnerability*. Methods in this category may look into the fabric of society to assess its preparedness and coping/adaptive capacity. A wide range of factors may be considered and there is no generally accepted methodology that covers all aspects of social vulnerability. A review of methodologies can be found in [11].

One central role in social vulnerability assessment is attributed to indicator based methods. In [11] a vulnerability *indicator for natural hazards* is defined as as ‘a variable which is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event linked with a hazard of natural. Social and environmental indicators research is common in the field of sustainable science. For example, United Nations Development Program’s Human Development Index [30], proposes a composite indicator of human well-being, as well as gender disparity and poverty among nations. Similarly, the World Bank develops indicators that stress the links between environmental conditions and human welfare, especially in developing nations, in order to monitor national progress toward a more sustainable future [31]. In natural hazards risk management framework, many of the indicator based vulnerability studies are relying on measuring attributes or factors influencing vulnerability rather than understanding relationships or processes [32].

The composition and selection of vulnerability indicators is complex. Ideally, there are nine different phases in the development of indicators (Figure 6) [33]: first, a relevant *goal* must be selected and defined. Then, it is necessary to perform a *scoping process* in order to identify the target group and the associated purposes for which the indicators will be used. The third phase presumes the identification of an appropriate *conceptual framework*, which means structuring the potential themes and indicators. The fourth phase implies the definition of *selection criteria* for the potential indicators (see below). The fifth phase is the *identification of a set of potential indicators*. Finally, there is the evaluation and selection of each indicator (phase 6) taking into account the criteria developed at an earlier stage, which results in a final set of indicators. The outcome of previous phases must be validated against real data, which in many cases proofs to be the most challenging part of the process due to difficulties in measuring or quantifying some of the intangible elements or aspect of vulnerability (e.g. social cohesion, confidence, etc.). The last phases of the indicator development imply the preparation of a report and assessment of the indicator performance which may results in a re-evaluation of the results (iterative process).

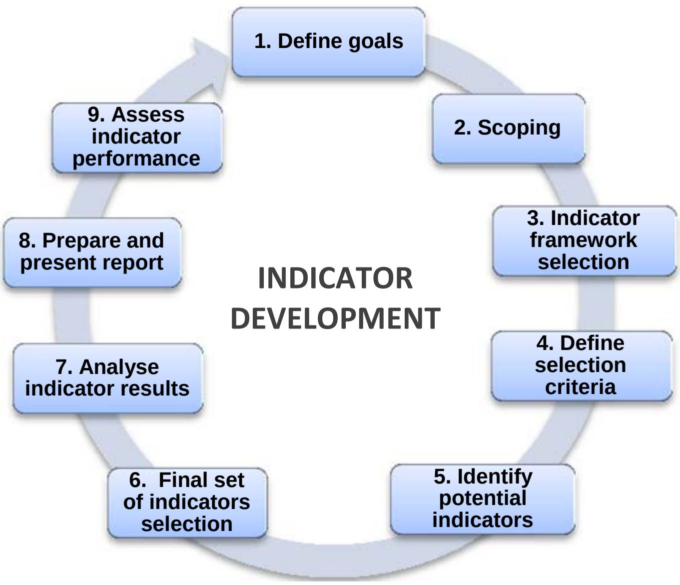

Figure 6. Development process of vulnerability indicators (based on the general figure according to [33] in [11])

Some important quality criteria for indicator and indicator development, as presented in [34], are: sensitivity (sensitive and specific to the underlying phenomenon), relevance, measurability, analytical and statistical soundness, validity/ accuracy, reproducibility, and cost effectiveness. The indicators should also measure only important key-elements instead of trying to indicate all aspects, and permit data comparability (across areas and/or over time).

In order to facilitate the use of indicators for decision-makers and summarize complex or multi-dimensional issues, sets of indices or composite indicators were developed. These are mathematical combinations of sub-indicators that can be easier to interpret than trying to find a trend in many separate indicators. However, there are no generally accepted methods of index aggregation (index construction) and their interpretation is not unique. An extensive description of construction methods and issues related with the combination of indicators is presented in [34].

An example set of factors used to assess social vulnerability at country level based on four main indices is [11]:

- *Disaster Deficit Index* (DDI; expected financial loss and capacity). The key factors describing economic resilience are insurance and reassurance payments, reserve funds for disasters, aid and donations, new taxes, budgetary reallocations, external credit and internal credit.
- *Local Disaster Index (*LDI; cumulative impact of smaller scale natural hazard events). A uniform distribution of disasters in the area under consideration gives a high value, whereas a high concentration of disasters in a low number of places a low value.
- *Prevalent Vulnerability Index* (PVI; composed of exposure, socio-economic fragility and lack of social resilience). Each of the three components has eight sub-indices. The indices are for example related to population and urban growth, poverty and inequality, import/exports, arable land/land degradation, unemployment, debts, human development index, gender inequality, governance and environmental sustainability.
- *Risk Management Index* (RMI; disaster management/mitigation strategies/systems). This index is composed of four factors estimating capacity related to risk identification, risk reduction, disaster management and financial protection. Sub-indices are related to the quality of, amongst others, loss inventories, monitoring and mapping, public information and training, land use planning, standards, retrofitting, emergency planning and response, community preparedness, reconstruction, decentralized organization and budget allocation.

2.3.2. Physical vulnerability assessment

If in social vulnerability assessment the focus is on determining the indicators of societies' coping capacities to any natural hazard and identifying the vulnerable groups or individuals based on these indicators, in physical (or technical) vulnerability assessment the role of hazard and their impacts is emphasized, while the human systems in mediating the outcomes is minimized. In the technical/engineering literature for natural hazards, physical vulnerability is generally defined on a scale ranging from 0 (no loss/damage) to 1 (total loss/damage), representing the degree of loss/potential damage of the element at risk (see Table 1). The evaluation of vulnerability and the combination of the hazard and the vulnerability to obtain the risk differs between natural phenomena. However, the majority of models see vulnerability as being dependent both on the acting agent (physical impact of a hazard event) and the exposed element (structural or physical characteristics of the vulnerable object). The most common expressions of physical vulnerability for different types of hazards (landslides, floods, earthquakes) are: vulnerability curves (stage-damage functions), fragility curves, damage matrices and vulnerability indicators [35]. In recent decades, research on flood vulnerability assessment has advanced substantially (especially with the aid of computational techniques) and different modeling approaches ranging from post-event damage observations to laboratory-based experiments and physical modeling have been developed. One major applications of flood vulnerability analysis is the development of guidelines for reducing structural vulnerability for different types of properties. Likewise, the results of these studies are used in spatial development strategies (spatial planning) and for identification of the elements or areas where damages would be expected in case of flood occurrence. There are two main approaches of flood vulnerability assessment: one (1) focuses on the economic damage and is essentially a quantification of the expected or actual damages to a structure expressed in monetary terms or through an evaluation of the percentage of the expected loss; (2) the other, deals with the physical vulnerability of individual structures and on the estimation of the likelihood of occurrence of physical damages or collapse of a single element (e.g. a building). Within the last category, two general methods can be identified:

Empirical methods are based on the analysis of observed consequences (collection of actual flood damage information after the event) through the use of interviews, questionnaires and field mapping. The main advantage of these methods is the use of real data. However, the results are very much dependent on the respondents' risk perception for the first two - and data availability (especially for deriving stage-damage curves) for the last collection method.

In **analytical methods** (i) different flood parameters (duration, velocity, impact pressure, etc.) are directly controlled during laboratory experiments and their effects on the structures are quantified; (ii) numerical models and computer simulation techniques are used to estimate the reliability of a structure and/or calculate its probability of failure (usually hydrologic and hydraulic modeling of the floodplain is a pre-requisite) [36]. This type of approaches are resource demanding (time and money) but allow for a better understanding of the relation between flood intensity and degree of damage for an exposed structure with definite characteristics. Moreover, due to data/resources requirement, they can only be used for assessment of individual structures.

The key parameters used in order to quantify physical vulnerability to floods are related with the forces (buoyancy, hydrostatic pressure and dynamic pressure) that flooding is likely to exert on a structure (e.g. building, bridge, dam, etc.). Directly linked with these forces are the characteristics of the damaging agent (water) which are reflected in a number of actions on the exposed structure: hydrostatic, hydrodynamic, erosion, buoyancy, etc. ([37] in [38]).

The most used approach for assessing and modeling direct flood damages is the stage-damage functions which relates the relative or absolute damage for a certain class of objects to the inundation depth (Figure 7). One limitation in their use is the assessment of the degree of damage based solely on one characteristic of the exposed element/group of elements (e.g. building type). Likewise, the flood damage influencing parameter e.g. inundation depth, may not be the only hazard indicator that contributes to the quantity of losses [39]. In [40] the importance of further influencing factors like 'duration of inundation, sediment concentration, availability and information content of flood warning and the quality of external response in a flood situation' are emphasized. For static floods (slow moving water) the depth is considered to be sufficient for the analysis, but for dynamic floods, velocity is regarded as more important.

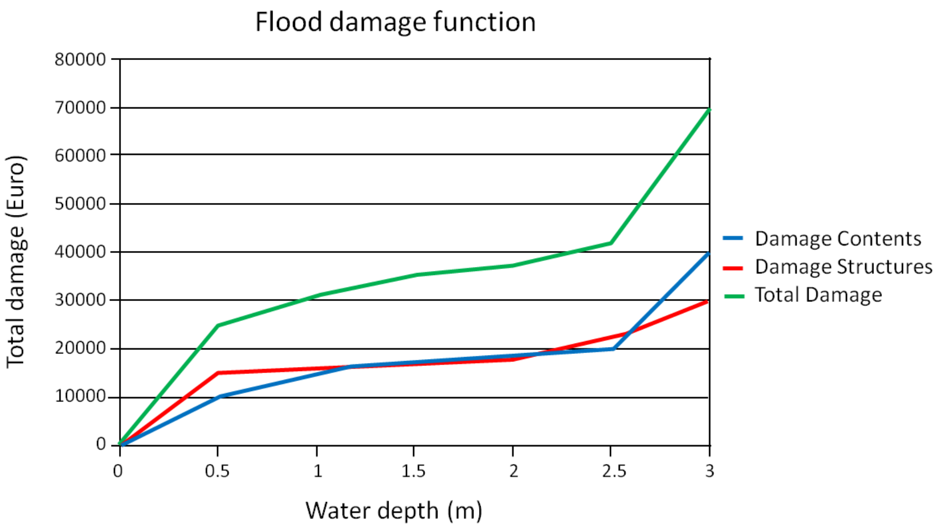

Figure 7. Example of flood damage curves showing damage to structures, contents and total damage as a function of inundation depths [41]

In HAZUS-MH Flood Model [42] the latter parameter is directly considered. A velocity-depth function is included indicating if building collapse has to be assumed. A threshold for collapse corresponding to 100% damage is set, while below this threshold the damage is estimated based on the inundation level only. The model also takes into account the effect of warning which is assessed based on a 'day-curve'. If a public response rate of 100% is assumed, a maximum of 35% of damage reduction can be achieved depending on the time of warning [26]. The flood hazard module addresses both riverine and coastal floods; flash-floods are not included in the model's capability.

The Swiss risk concept from the Nationale Platform Naturgefahren (PLANAT) defines three intensity classes for flood vulnerability analysis, based on flood depth and velocity which are used in spatial planning regulations (Table 2).

Intensity class	Criteria	Description
Low	h < 0.5 m or v x h < 0.5 m^2/s	Persons are barely at risk and only low damages at buildings or disruption have to be expected
Middle	2 m > h > 0.5 m or 2 m^2/s > v x h > 0.5 m^2/s	Persons outside of buildings are at risk and damage to buildings can occur while persons in buildings are quite safe and sudden destruction of buildings is improbable
High	h > 2 m or v x h > 2 m^2/s	Persons inside and outside of buildings are at risk and the destruction of buildings is possible or events with lower intensity occur but with higher frequency and persons outside of buildings are at risk

Table 2. Intensity classes based on flood depth and velocity from PLANAT in [26]

Damages caused by landslides to population, environment and built-up areas are significantly less than for other natural hazards due to the inherent characteristic of the process. However, the extent of these losses is frequently underestimated especially when landslides are associated with the occurrence of floods or earthquakes (their consequences tend to be aggregated). Generally, vulnerability to landslides depends on a variety of factors like: runout distance; volume and velocity of sliding; pressure caused by the movement; height of deposition; elements at risk (e.g. different structures), their nature and their proximity to the slide; elements at risk (e.g. persons), their proximity to the slide, the nature of the building/roads they are in [43].

Research in the field of landslide hazard and risk ([24], [44], [45],[46]) has demonstrated that in contrast to other natural processes (flooding, earthquakes) landslide vulnerability is more difficult to assess due to a number of reason, such as:

i. The complexity and the wide range of variety of landslide processes (landslides are determined by different predisposing and triggering factors which results in various mechanisms of failure and mobility, size, shape, etc.)

ii. The lack of systematic methods for expressing landslide intensity - there is no general indicator of landslide intensity (e.g. for rock falls, impact pressure or volume can be used whereas for debris flow deposit height is common; other indicators such as flow velocity are rarely considered) and in practice data scarcity reduces their number significantly

iii. The quantitative heterogeneity of vulnerability of different elements at risk for qualitatively similar landslide mechanisms due to their intrinsic characteristics (here, human life constitutes a special case)

iv. The variability in spatial and temporal vulnerability

v. The lack of historical damage databases – usually only events which cause extensive damage are recorded and data about the type and extent of damage is often missing

vi. Non-physical factors influence the vulnerability of people (e.g. early warning, hazard and risk perception, etc.)

Landslide vulnerability assessment approaches range significantly due to various foci and objectives addressed. Some consider vulnerability within the landslide risk management framework, others evaluate exclusively physical vulnerability. Three general types of methodologies can be identified (without excluding the possibility of other classification schemes):

Qualitative methods ([47], [48], [35]) - given a particular landslide type and the characteristics of the elements at risk, the appropriate vulnerability factor is assessed by expert judgment, field mapping or based on historical records. These methods are flexible (e.g. indicator based methods) valuable and easy to use/understand by decision makers. However, a major limitation of this approach is that most of the data have to be assumed and there is no direct (quantified) relation between hazard intensities and degree of damage.

As an example, in [47] an empirical GIS-based geomorphological approach for landslide and risk analysis was proposed, using stereoscopic aerial photographs and field mapping in order to represent the changes in distribution and shape of landslides and assess their expected frequency of occurrence and intensity. The damages were classified in three classes using a qualitative relationship between landslide intensity/type and their consequences: *superficial* (aesthetic, minor) damage where the functionality of the elements at risk is not compromised and damage can be repaired, rapidly and at low costs; *functional* (medium) damage, where the functionality of the structures is compromised, and the damage takes time and large resources to be fixed; *structural* (total) damage, where buildings or transportation routes are severely or completely damaged, and require extensive (and costly) work to be fixed (demolition and reconstruction may be required).

Semi-quantitative methods are reducing the level of generalization in comparison with qualitative methods. They are flexible and can, to a certain degree, reduce subjectivity, compared with the methods mentioned above. Within this category, damage matrices, for example, are composed by classified intensities and stepwise damage levels. In [49] damage matrices were suggested based on damaging factors and the resistance of the elements at risk to the impact of landslides. Figure 8 shows a correlation, in terms of vulnerability, between exposed elements and the characteristics of the hazard. The applicability of this method, requires statistical analysis of detailed records on landslides and their consequences [50]. This proves to be a challenge in data scarce environments.

Quantitative methods ([51], [52], [53], [54]) are mostly applied at local scale (often, for individual structures) due to complexity of procedures involved and detailed data requirements. Quantitative methods are usually employed by engineers or actors involved in technical decision making, as they allow for a more explicit objective output. The results can be directly integrated in a Quantitative Risk Assessment (QRA) also taking into account the uncertainty in vulnerability analysis. The procedures involved can rely on i) expert judgment (heuristic), ii) damage records (empirical) or iii) statistical analysis (probabilistic).

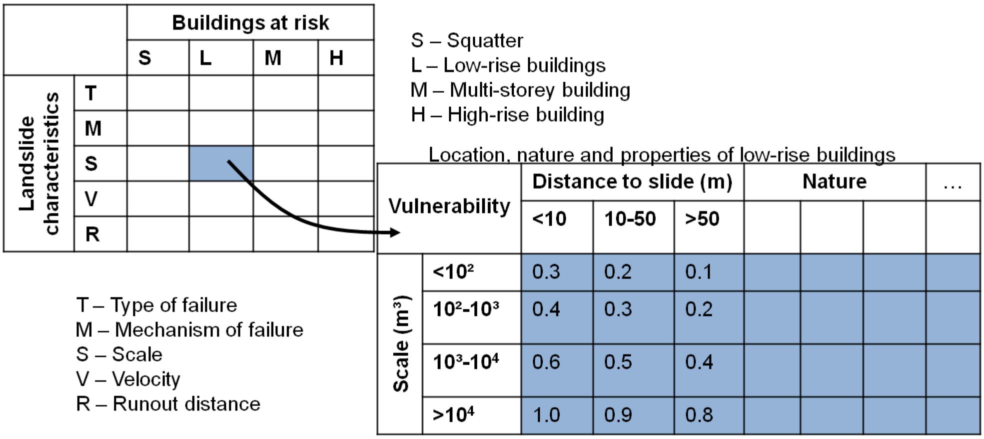

Figure 8. Structural vulnerability matrix [49]

One example of quantitative expert judgment used to evaluate physical vulnerability of roads to debris flows was used in [55]. 147 respondents from 17 countries were asked to use their expert knowledge to assess the probability of a certain damage state being exceeded given that a volume of debris impacts a road (Table 3).

Description of probabilities		
Descriptor	**Description**	**Values for analysis**
Highly improbable	Damage state almost certainly exceeded, but cannot be ruled out	0.000001
Improbable(remote)	Damage state only exceeded in exceptional circumstances	0.00001
Very unlikely	Damage state will only be exceeded in very unusual circumstances	0.001
Unlikely	Damage state may be exceeded, but would not be expected to occur under normal circumstances	0.001
Likely	Damage state expected to be exceeded	0.01
Very likely	Damage state almost certainly exceeded	0.1

Table 3. Damage state definition [55]

Based on the questionnaire results, fragility curves were produced which relate the flow volume to damage probabilities (Figures 9). It should be noted that in this study probabilites were derived based on the respondents experience only (qualitative data) with no statistical processing of damage observations or analytical/numerical modeling. The results were compared to known events in Scotland (UK) and the Republic of Korea. The major limitation of this method is the high degree of subjectivity, however it advances expert knowledge which might be in some cases the only/most appropriate source of information about damages caused by the impact of landslides.

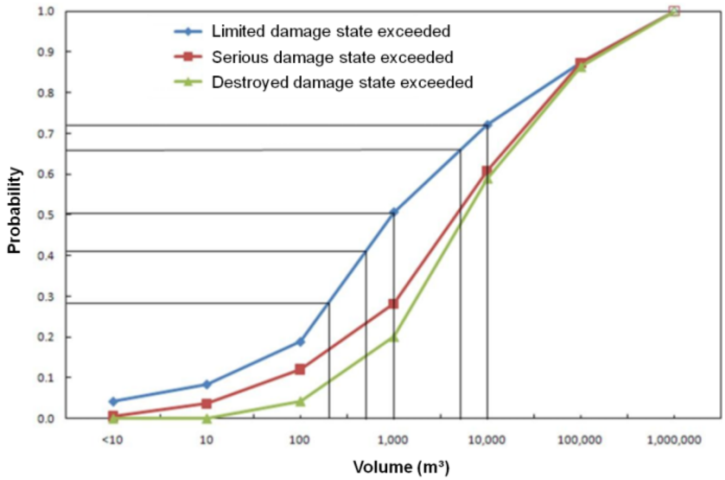

Figure 9. Fragility curves 'forced' to unity and manually extrapolated to the next order of magnitude for volume (local roads). The vertical lines are added at 200, 500, 1000, 5000 and 10000 m^3 (illustration only for 'limited damage' curves) [55]

In reference [53], the author performed a study of a well-documented debris flow event which occurred in the Austrian Alps (August, 1997) and derived vulnerability curves for buildings located on the fan of the torrent based on the intensity of the phenomenon and the damage ratio. The intensity was approximated by deposit height and the susceptibility of the element at risk (i.e. buildings) by material of construction (brick, masonry, and concrete). Figure 10 shows the curve produced together with other existing curves for comparison. The application of this vulnerability function is limited to process intensities expressed as deposit height ≤ 2.5 – 3 m which means that the curve is not relevant for intensities which exceed this value. Nevertheless, the authors argue that such high process intensities generally result in a total loss of the building since the reparation costs will exceed the expenditure necessary for a new construction [53].

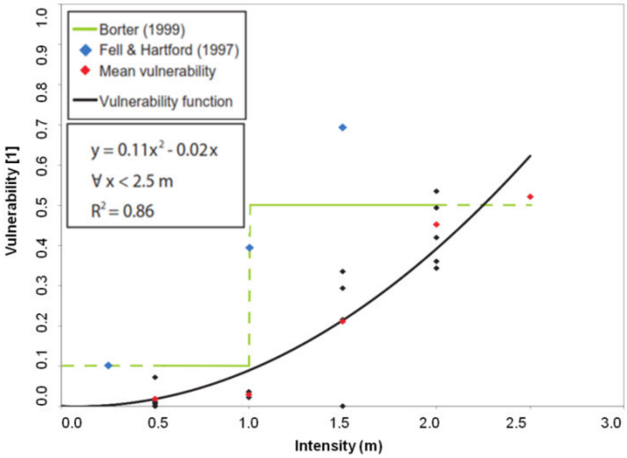

Figure 10. Relationship between debris flow intensity and vulnerability is expressed by a second order polynomial function for flow height > 2.5 m. Results from the study are indicated by black dots, the corresponding mean vulnerability is indicated by red dots [53]

In another study [51], a scenario-based method derived from a probabilistic approach to regional vulnerability assessment [56] was used. The authors defined vulnerability as a function of landslide intensity and the susceptibility of vulnerable elements (see Eq. 2).

$$V = I \bullet S \tag{2}$$

Susceptibility is defined as 'the lack of inherent capacity of the elements in the spatial extension under investigation to preserve their physical integrity and functionality in the course of the physical interaction with a generic sliding mass' and is independent of the characteristics of the landslide [51]. The susceptibility model is able to accommodate any factor dictated by the analyzed category of elements at risk. In this study, the susceptibility factors taken into account are: (a) resistance and state of maintenance for structures, and (b) persons in open space and vehicles, population density, income, age, and persons in structures, for individuals. For landslide intensity, a composite parameter is derived based on the kinetic – (related with the damage caused by the impact energy of the sliding mass) and kinematic (accounts for the effects of size-linked features of a reference landslide) characteristics of the interaction between the sliding mass and the reference area proposed. Models for quantification of susceptibility (Eq. 2) and intensity (Eq. 3) are illustrated below:

$$S = 1 - \prod_{i=1}^{ns} (1 - \vartheta i) \tag{3}$$

where,

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ϑi is the i-th on ns susceptibility factor (each defined in the range) contributing to the category susceptibility

and,

$$I = ks \bullet (rK \bullet IK + rM \bullet IM) \tag{4}$$

where,

ks is the spatial impact ratio (equal to the ratio between the area pertaining to the category that is affected by the landslide and the total area pertaining to the category); rK and IK are kinetic factors and rM and IM are kinematic factors. The proposed methodology provided a framework for the quantification of uncertainties in vulnerability assessment.

3. Uncertainty in vulnerability analysis

In natural hazards risk management, decisions regarding the risk associated with a particular hazard are essentially enacted based on limited information and resources. In order to improve this process, experts started to investigate the effects of uncertainty on risk (and its determinants) qualitatively or quantitatively and communicate their results to decision-makers. This one-way approach toward finding solutions for advancing decision making proves out to be insufficient in contrast to the complexity of the problems at hand, especially when dealing with inherent uncertainties or unforeseen changes in the human-environmental system. Nevertheless, effort are being made to reduce the effects of uncertainty on vulnerability (and consequently, risk), particularly related with the data and models used. For example, representing hazard damage potential by only one parameter (e.g. for floods – depth of inundation) can result in overestimations of vulnerability and subsequently in un-economic investments in mitigation countermeasures. One possibility to overcome this problem would be to reduce the uncertainty in the input data by using data-mining approaches (e.g. tree-structured models) for the selection of the most important damage-influencing parameters [39]. Other examples would be the use of scenario analysis for seismic vulnerability and its probable damages in order to develop a hierarchy of effective factors in earthquake vulnerability [57] or testing the performance of different structures (reliability analysis) subjected to the impact of landslides with various intensities through the use of traditional methods like Monte Carlo Simulation (MCS), First Order Second Moment (FOSM), First Order - /Second Order Reliability Method (FORM/SORM). However, the selection of the most appropriate uncertainty modeling approach depends on the level of complexity required by the scope of analysis or the use of the final results.

Generally, uncertainties in decision and risk analysis can be divided into two categories [10]: those that stem from 'real' variability in known (or observable) processes or phenomena (e.g. height or the ethnicity of an arbitrary individual in a specified population or the distribution of velocities in a sliding mass, etc.) and those which reside from our limited knowledge about fundamental phenomena (e.g. the nature of some earthquake mechanism, the effect of water level fluctuation on clay slope stability, etc.). The former is known as aleatory (inherent or stochastic) uncertainty and cannot be reduced. The latter, epistemic uncertainty, includes measurement uncertainty, statistical uncertainty (due to limited information), and model uncertainty, which can be reduced, for example, by increasing the probing samples or by improving the measurement methods or modeling algorithms. Other types of classification systems, together with a review of methods and simulation techniques for uncertainty treatment are critically discussed and illustrated in a work performed by the Norwegian Geotechnical Institute (NGI), in [34]. Uncertainty can be addressed from (1) an integrative perspective, where vulnerability is registered by exposure to hazards but also resides in the resilience of the system experiencing the hazard [58] (bottom-up oriented vulnerability assessment). In this context, uncertainty is associated with future changes (in frequency and magnitude of hazards but also in climatic, environmental and socio-economic patterns) characterized by unknowable risks to which communities must learn to adapt. This approach is centered on the human systems' coping capacity and promotes vulnerability reduction through enhancing resilience to future change. Conversely, (2) a direct approach towards reduction of (epistemic) uncertainty is developed within the technical field (assimilated to deductive, top-down vulnerability assessments), where uncertainty models are defined for each component of vulnerability and the sources of uncertainty categorized [45]. Figure 11 shows how these two approaches of dealing with uncertainty can inform climate adaptation policy: one is (epistemic) uncertainty 'reducer' while the other is uncertainty 'accepting' (due to issues like, for example, timescale and planning horizons, the unit of analysis being considered and the development status of the region or country) [59].

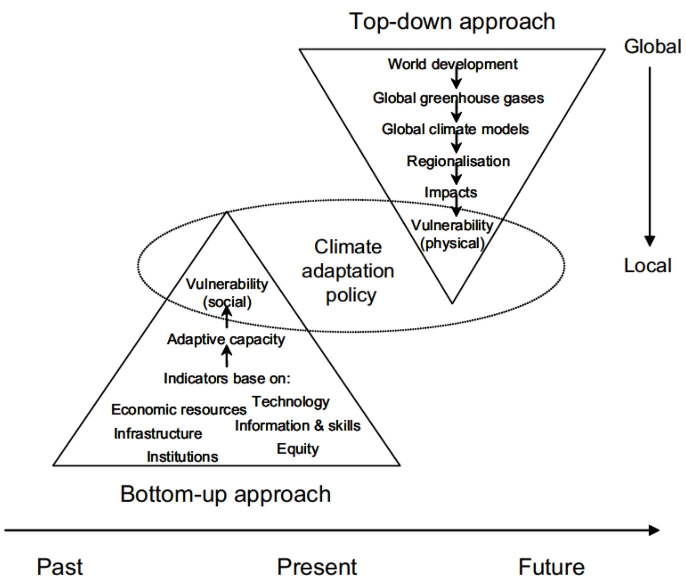

Figure 11. "Top-down" and "bottom-up" approaches used to inform adaptation to climate change [59]

Table 4 illustrates an example of uncertainty sources in physical vulnerability analysis of buildings. It is obvious that these will vary with the methodology used and the quality and quantity of data available.

Type	Source
Epistemic	Intensity assessment (using proxies e.g. depth of material, velocity, volume, impact pressure, etc.) Characterization of elements at risk (e.g. structural-morphological characteristics, state of maintenance, strategic relevance, etc.) Estimations of buildings' value and damage costs Vulnerability model (selection of parameters, mathematical model, calculation limitations) Expert judgement
Aleatory	Spatial variability of parameters* (e.g. landslide intensities, population density, etc.)

*also related with the scale of investigation

Table 4. Sources of uncertainty in physical vulnerability to landslides (e.g. for buildings)

Within the general risk assessment framework, uncertainty propagates not only from one component of risk to another but also within the process stages of vulnerability analysis. This is schematically described in a classification system for vulnerability estimation proposed in [34] and represented in Figure 12.

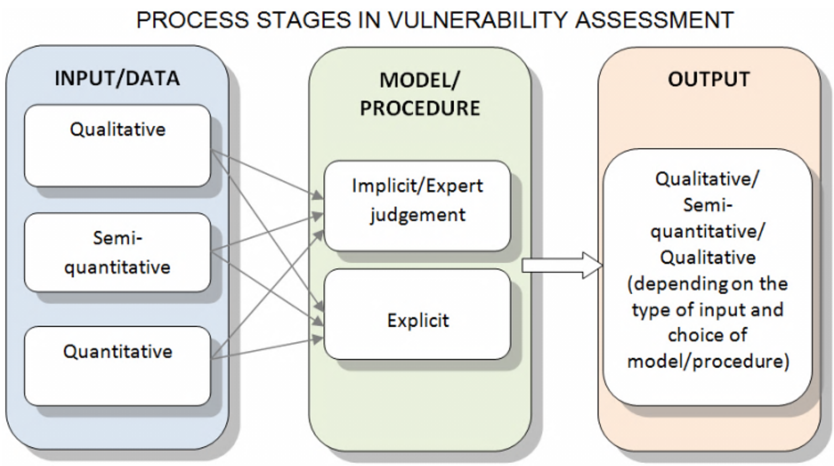

Figure 12. Classification system for vulnerability estimation. Uncertainty is associated with each process stage [34]

According to the authors, uncertainty associated with the input data (depending on the type, quantity and quality), propagates through the model, which also contains a degree of uncertainty due to, for example, expert judgment, mathematical model or basic assumptions. The uncertainty in the output depends on the two previous process stages as well as the uncertainty related with the interpretation of the results.

4. Conclusions

The most important goal in developing tools for measuring vulnerability is their use in natural hazards risk reduction strategies, thus applying them in decision making processes. In this context, it is necessary to know what is the objective of the assessment, what is the target group of any particular approach, who is using the results and what is their understanding of the outcome. The methods of vulnerability assessment presented herein are mere exemplification of the complexity and wide range of approaches that can be applied in natural hazards disaster risk management. However, based on these a number of observations may be formulated.

Vulnerability defined considering physical exposure or social-economical determinants only cannot encompass the complexity of effects caused by the impact of a natural hazard on an element or group of elements at risk (especially for systems like urban developments, communities, etc.). In an editorial for vulnerability to natural hazards [60] addressed the question of integration between natural and social scientific approaches based on a number of research studies. Their findings show that, studies that are dedicated to different components of vulnerability (e.g. frequency and magnitude of a hazard, elements at risk, exposure, coping and adaptation capacities, etc.) and therefore use different methodological approaches, are relatively similar in scope. Hence it is important to clearly describe and define which components of risk and/or vulnerability assessment are considered in each individual case study. The aim is to communicate without losing the perspective either of the approaches advances. Thus, a step forward towards an integrative vulnerability assessment might be to strengthen the dialogue between different groups of experts in natural hazard vulnerability/risk assessment through exchange of views about definitions, concept and underlying worldviews and values [60].

In terms of vulnerability/risk assessment outcomes, there are three main types of methods (results) - quantitative, semi-quantitative and qualitative, all with benefits and drawbacks. The main difference between quantitative and qualitative methods lies in the fact that quantitative assessments provide a more explicit objective framework which may be conducive to improving decision making process. However, the most appropriate tool depends on the decision problem at hand (for example, qualitative vulnerability assessment can be more cost effective, less time consuming and easier to understand for non-technical stakeholders), the objective (including scale) of the analysis and the quality/quantity of available data. Hence there is no general preference for qualitative, semi-quantitative or quantitative approaches [61]. One must also acknowledge that there is no quantitative vulnerability/risk assessment totally devoid of expert judgment; quantitative vulnerability/risk analysis rather provides a framework for making systematic judgment [62]. It is the quality and quantity of subjectivity that affects the overall outcome of the analysis.

With regards to uncertainty in vulnerability analysis, Gall [63] emphasizes the importance of knowledge quality assessment - 'uncertainty and sensitivity analysis are mandatory for maximizing methodological transparency and soundness, and hence the acceptance of research findings; despite this demand, both analyses are often missing in vulnerability assessment'. However, progress has been done, for example, in the field of technical (structural) vulnerability (mostly, for hazards like floods and earthquakes), where empirical as well as statistical (probabilistic) methods aided by GIS and advanced computational models are used to estimate uncertainty in vulnerability and its components.

To allow for an improved decision making process through the treatment of uncertainty, first the joint effort between end-users and experts must shift towards a more transparent, participative and open process. The role of the scientist seen as 'speaking truth to power' is defective as it implies that all uncertainties can be treated. Conversely, experts should clearly communicate the limitations of their findings as well as continue to investigate the effects of uncertainty on risk and its determinants in order support the community to face future challenges in dealing with natural hazards and risk and global change.

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REVIEW
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Hazards and disasters in the Anthropocene: some critical reflections for the future

Dale Dominey-Howes*

Abstract

The arrival of the Anthropocene presents many challenges—both theoretical and practical. Scholars in different disciplines, practitioners, the public and others, are all considering the meaning of the Anthropocene and how its arrival affects their ways of knowing and doing. Given that a dominant narrative of the Anthropocene is one of a coming crisis, hazard, and disaster experts from different disciplines have much to contribute. Here, I briefly summarize the trajectory of hazards' and disasters' research through to the present to provide the context to ask a series of critical questions that experts in hazard and disaster might address to make theoretical and practical contributions to making the Anthropocene as good as it might be. The questions considered are: how useful is the contemporary crisis narrative of the Anthropocene for understanding the planetary history of hazards and disasters, and coupled to this; is the modern language of disaster risk reduction useful for understanding past disasters; how do we give voice to the more-than-human experiences of Anthropocene disasters; is it possible to mitigate the impacts of future hazards and disasters within the Anthropocene without addressing the root causes of vulnerability; how do we make space for slow emergencies and what do slow emergencies mean for understanding hazard and disaster in the Anthropocene; and finally, does the scholarship of hazard and disaster provide evidence useful for informing the debate about an early or late-start for the Anthropocene?

Keywords: Hazards, Disasters, Emergencies, Anthropocene, Disciplinary contributions, Critical questions, Future

"The bright sun was extinguish'd….. And men were gathered around their blazing homes…. Of the volcanoes, and their mountain-torch; a fearful hope was all the world contain'd……. Famine had written Fiend….. Darkness had no need of aid…… She was the Universe"
(*Darkness*, Lord Byron, 1816)

Introduction

Much is being written about the arrival of the Anthropocene, a concept that if accepted, means we have entered a new epoch in Earth history (Ellis et al. 2016; Veland and Lynch 2016). This epoch is one in which for the first time in geological history, a single species—*Homo sapiens*—has emerged as a planetary scale force, shaping both the surface morphology of the planet and the functioning of the Earth system itself. In relation with the Anthropocene, key debates revolve around whether we have in fact, entered this new epoch, if we have, can we delineate a particular moment when it commenced (an early or late-start), what evidence can or might be used to delineate the boundary between the Holocene and the Anthropocene, will the Anthropocene be 'good' or 'bad' (in particular, for humanity), how might we limit the negative effects of human interference on the Earth system and humanity and how does the arrival of the Anthropocene challenge us as individuals, communities, and as a species? It is not my intention to repeat here the various debates, issues, and arguments related to them as a rapidly growing literature tackles these and other relevant questions. However, Fig. 1 presents these as a framework against which the questions asked here, intersect.

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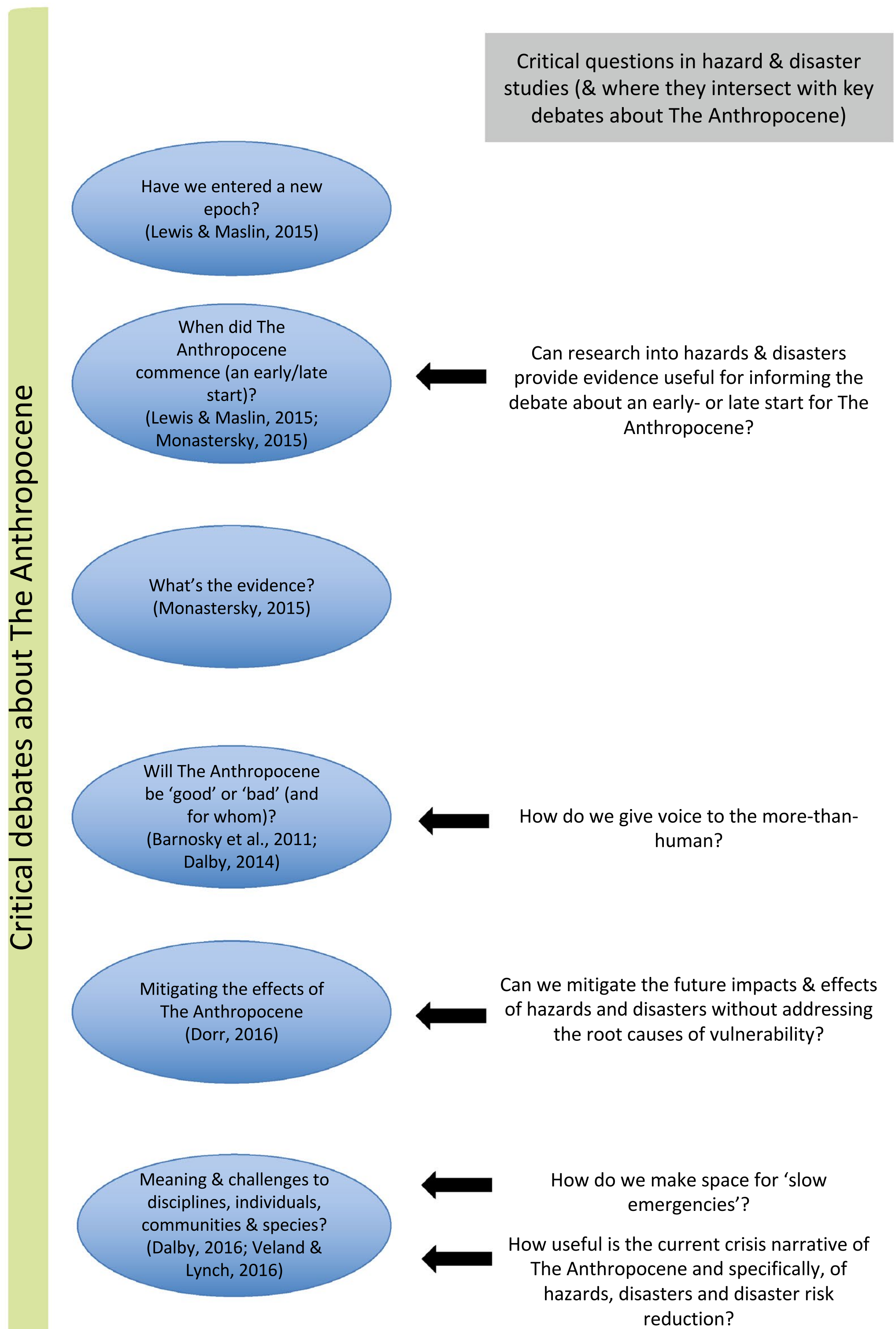

Fig. 1 Critical debates about the Anthropocene and reflective questions in hazard and disaster studies that intersect with these debates

Commentators suggest that the arrival of the Anthropocene challenges established academic disciplines to reimagine their thinking and knowledge and to ask deep and critically reflective questions (Dalby 2016). Furthermore, experts within different disciplines can make unique contributions to understanding the meaning and significance of the Anthropocene, including critically, the social sciences (Ellis et al. 2016), despite recent claims to the contrary (Hamilton 2016). I specialize in hazard and disaster studies having trained in 'earth hazard geosciences' and 'disaster risk reduction'. Earth hazard geosciences span the interface of the earth and human and social sciences. The former is generally concerned with an analysis of potentially hazardous events and processes such as earthquakes, tsunamis, droughts, bushfires, and so on, seeking to understand their causes, processes, distributions, frequencies, magnitudes, intensities, past histories, likely future occurrence, impacts, and effects (Arora and Malik 2017; Hyndman and Hyndman 2014; Nott 2016; Somerville 2014). Experts are interested in observing, measuring, monitoring, modelling, and forecasting these potentially hazardous events. This work intersects with, and helps to inform the disciplinary work of land use and urban planners together with engineers who seek to develop and build resilient places and structures. The latter is more concerned with understanding the underlying social, political, economic, cultural, religious contexts, and other structures, processes, and conditions that operate in relational scales from the local to the global that result in potentially hazardous events becoming actual disasters (Wisner et al. 2004). Such human and social work goes further in that it also seeks to understand how we might create and enable more resilient communities, empower people to reduce their own vulnerability, and live with and tolerate risk, thus also contributing to the work of disaster risk reduction (Nunn 2014; Satake 2014). Clearly, to address such a wide range of issues and topics, hazard and disaster studies necessarily draws upon experts, knowledge, theories, philosophies, methods, tools, and approaches from a variety of established and emerging academic disciplines (Fig. 2). Although Fig. 2 presents these as distinctive disciplines, in truth, the boundaries between them are blurred with experts often crossing between them, deploying theories, approaches, tools, and methods from closely related fields.

This paper is a response to the challenge of asking what can scholarship—in this case, in *hazard and disaster studies*, contribute to our understanding of the Anthropocene? This is important, because the most negative of the dominant Anthropocene discourses is one of crisis, disaster, insecurity, and a rapidly destabilizing planet (Clark 2014). Such a paper could take many forms and directions. However, here, five critical review questions that can help make sense of the Anthropocene and explore its meaning for the professional work of hazard and disaster theorists and practitioners are presented. The purpose of articulating these questions and presenting a response is to provoke thinking and robust discussion and to encourage other experts of hazard and disaster across the disciplines to expand upon them and to identify others not examined here.

The first question considered is how useful is the contemporary 'crisis narrative' of the Anthropocene for understanding the planetary history of hazards and disasters, and is the modern language of disaster risk reduction useful for understanding past disasters? Second, how do we give voice to the more-than-human[1] experiences of disaster in the Anthropocene? Third, can we avoid or prevent the worst impacts of future hazards and disasters within the Anthropocene without addressing the root causes of vulnerability? Fourth, with all the noise and media flare of the 'rapid and sudden onset disaster', how do we make room for recognizing, understanding, and addressing 'slow emergencies' and what do slow emergencies mean for understanding hazard and disaster in the Anthropocene? Finally, can experts of hazard and disaster contribute to the debate about the early or late-start date for the Anthropocene?

Before addressing these questions, I provide a short review of the fields of hazards, disasters, and disaster risk reduction to elucidate the research trajectory that has brought us to where we are today, and how the contemporary fields of hazard and disaster are built upon the expertise of numerous disciplines. This establishes the foundations that bring me to ask the five critical review questions posed.

Brief review of the research trajectory of the fields of hazards, disasters, and disaster risk reduction

Questions about and research into hazards and disasters is not new. Throughout history, individuals have explored and written about hazard events and disasters. Ideas about hazards and disasters may be broadly grouped into the 'pre-enlightenment' and 'post-enlightenment' periods.

Early pre-enlightenment work, at least in the west, focused on the ideas of pre-Socratic philosophers such as Homer who argued hazards and disasters were caused by the Gods as punishment for our wrong doing and who placed demands on the mortal. Our responses to these

[1] In this paper, I refer to the 'more-than-human' as including two elements. First, is all other non-human species—that is plants and animals. Second, at a broader level and consistent with social science thinking, I refer to whole ecological and physical environments as 'more-than-human'.

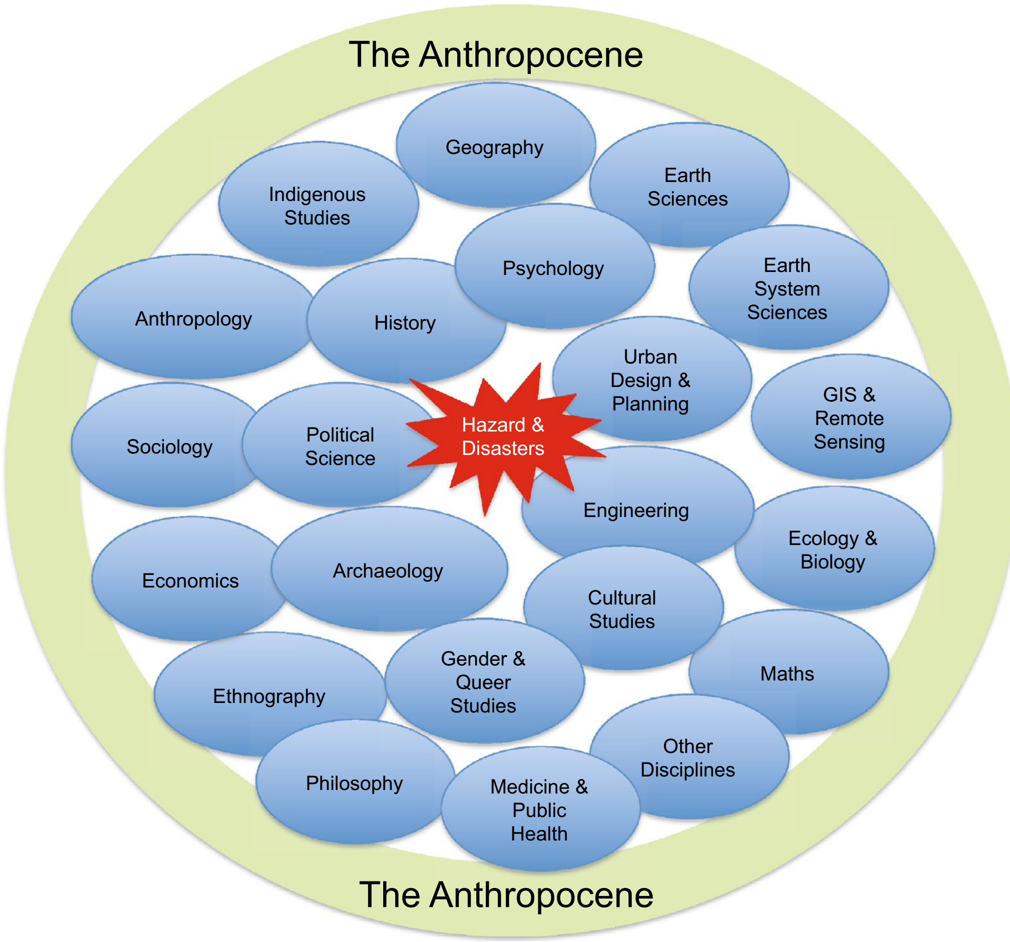

Fig. 2 Wide range of disciplines contribute to the study of hazards and disasters and all have contributions to make to help us understand the significance of possible hazards and disasters in the Anthropocene

determined our positions in the afterlife. These works did not explore the possibility of earth system processes as the cause of hazards and disasters. This thinking shifted with later Classical Philosophers such as Plato, and Strabo, who speculated about natural world processes' causing hazards and disasters. Starbo in his work *Geograhica* explored the physical and political geography of his world. Within *Geograhica* are references to various natural hazards. Strabo considered that earth processes might be responsible for some of the extreme events experienced by communities that he visited and learnt about.

Western thinking shifted abruptly following the Lisbon earthquake and tsunami of 1755. As the enlightenment unfolded, philosophers such as Voltaire asked deeply reflective and critical questions about the nature of hazard and disaster, proposing the causes as a hybrid between processes occurring in the natural world coupled with concepts of faith and religion (Dynes 1999). These ideas were hotly contested. Interestingly, a combination of Voltaire's thinking and the consequences of the 1755 Lisbon disaster resulted in the development of the discipline we now call 'seismology'.

From the 17th to early 20th centuries, there was a rapid development of the scientific method and thinking, and the field of geology emerged and contributed much to our understanding about hazards and disasters. Debates raged between religious (Christian) explanations for hazards and disasters attributing them to divine punishment and scientific explanations attributing them to earth system processes, the causes of which were speculated upon. Geological work resulted in the idea of 'catastrophism', later contested and abandoned and perhaps recently, refound. Description of the natural world was followed by the development of theories, followed by exploration for evidence and measurement. With the arrival of the 21st century, fields such as geology have moved to numerical modelling and forecasting.

The 20th century began with a more-or-less exclusive scientific framing of hazards and disasters—consequences of the classification of the Earth into four systems (the atmosphere, the lithosphere, the hydrosphere, and the biosphere) (Smith and Petley 2009). However, two seminal works laid the modern foundations for the study of hazards and disasters—Prince (1920), White (1945).

In 1917, a military ship loaded with explosives moored in Halifax Harbour caught fire and exploded. The explosion was so large and it caused a major habourside fire and a tsunami. Over 2000 people were killed. Prince (1920) sought to understand this disaster and for the first time, he explored the role of human behaviour and decision-making in how the events unfolded. This socio-behavioural approach was the first of its kind and laid the foundations for understanding human contributions (the social dimension) of hazards and disasters. This work, however, focused on a technological disaster. This was followed by an enormously influential study by Gilbert White (White 1945). White, a Geographer based at the Chicago School, explored human dimensions and adjustments to floods in the United States and realized that disasters were really a sociological process, whereby underlying aspects of vulnerability due to political, planning, economic, and other socio-demographic processes amplified vulnerability to hazards—in the case of floods triggered within the earth system.

From the mid-20th century, the field of hazard and disaster research splintered into two major paradigms: the 'hazards' and the 'alternative'. The hazards paradigm captured the physical and engineering sciences and the alternative hazards paradigm focused on (successively), behavioural, development, and complexity sciences (Smith and Petley 2009). The hazards paradigm places emphasis on the physical environment with earth scientists, physical geographers, physicists, mathematicians, and other closely related discipline experts driving forward research into the physical processes of hazards, their occurrence, mechanisms, frequencies, and behaviours. Here, vulnerability to hazards is viewed as a linear, negative outcome of exposure to a hazard, measured potential of impact and loss, and realized impacts of hazards. Geophysical agents are the focus. This led to the involvement of engineers, urban planners, and other experts exploring ways their fields might mitigate the risks associated with hazards prompting the development of highly technocratic solutions to risk and disaster management. Despite the best efforts of these physical and engineering fields, their efforts failed and people continued to die and losses increased across the planet.

This prompted the alternative paradigm combining political economy and political ecology with traditional physical system approaches. Consequently, research focused on investigating hazard, risk, and vulnerability in a societal context. The main aims have been to understand the underlying political, behavioural, social, economic, religious, and other societal processes that influence vulnerability and reduce resilience to hazards and disasters. Experts from anthropology, sociology, geography, history, economics, and political sciences, amongst others, have made major contributions. From the 1970s onwards, a succession of theoretical models from behaviour to development to complexity has been advanced by researchers across a number of disciplines that collectively, greatly improve our understanding (Smith and Petley 2009). The evolutionary path and interrelationships between these models are shown in Fig. 3. With time, these models have evolved in complexity and have become attentive to the interconnections between natural environments and human societies and the feedbacks between them, at a range of scales from the local to the global. These models and approaches have evolved into those referred to as coupled human–environment systems. The current dominant approaches include vulnerability science (Adger 2006; Calgaro 2010) and resilience (Alexander 2013) with a newly emerging field called 'transformation' (Pelling et al. 2015). These approaches are significant because to truly understand the complexity of hazards and disasters, teams of interdisciplinary experts come together from across the physical-engineering-human sciences domains. The current United Nations International Strategy for Disaster Risk Reduction calls for such interdisciplinary work.

Having briefly reviewed this evolutionary trajectory, it should be immediately clear that scholars of hazard and disaster have much to contribute to understanding the meaning of the Anthropocene—especially given the crisis narrative that pervades much of the discourse.

Five questions for scholars of hazard and disaster to consider in relation with the Anthropocene

How useful is the contemporary crisis narrative of the Anthropocene for understanding the planetary history of hazards and disasters and, is the modern language of disaster risk reduction useful for understanding past disasters?

The narrative of the Anthropocene is one of a slowly, but increasingly rapid, unfolding process that in all probability will manifest as a catastrophe for the sustainability of the planet, its ecological systems, human and more-than-human inhabitants (Dalby 2014; Lewis and Maslin 2015; McKinnon 2017; Monastersky 2015; Rockstrom et al. 2009). The Anthropocene marks the arrival of a time characterized as not providing a 'safe operating space for humanity' (Rockstrom et al. 2009). The narrative

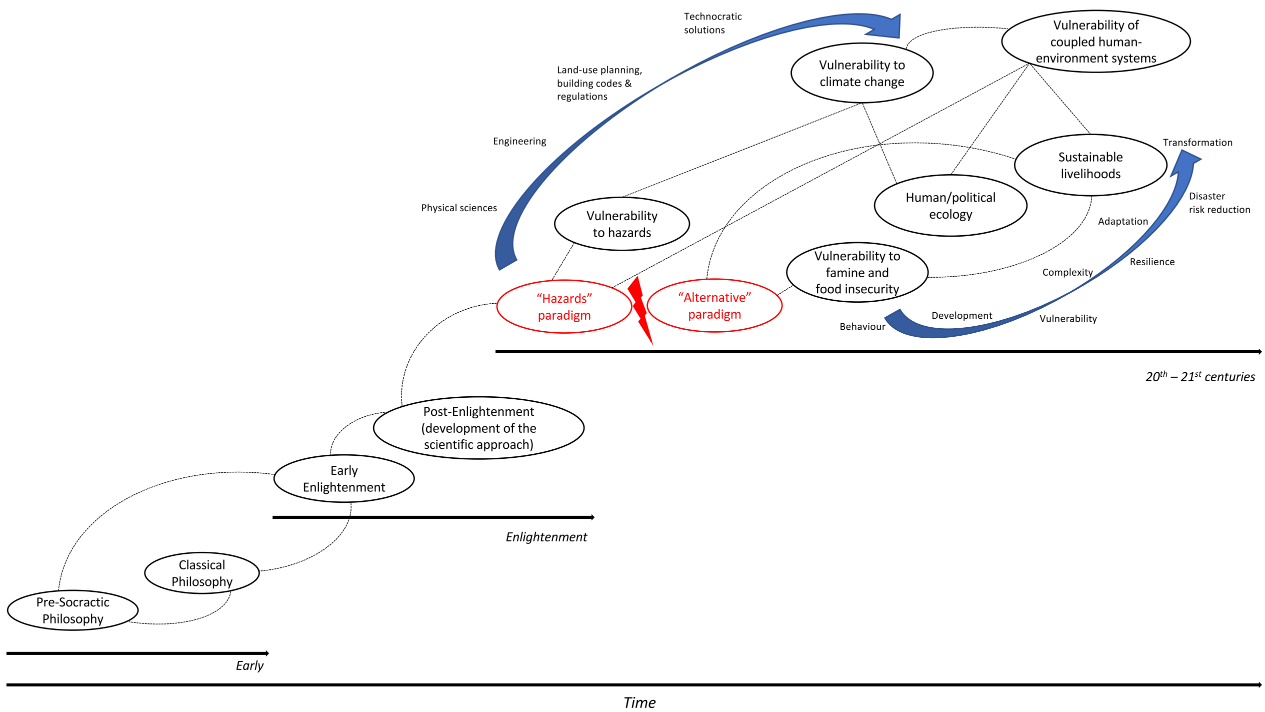

Fig. 3 Evolution of philosophical paradigms, concepts and approaches to the study of hazards and disasters. These might loosely be thought of as occurring in three stages: early, the enlightenment and the 20th and 21st centuries

presents the cataclysmic consequences of the Anthropocene as a contemporary and *novel* event in the history of the planet. The focus on the present and the future gives preference to these time periods and the framing of that trajectory as a specific 'disaster'. It denies the deeper history of events that may be labelled as 'disasters' that have affected Earth, from which the planet *has* survived (Albritton 1989; Reimoldy and Jourdan 2012). Significant regional and planet-wide catastrophes have occurred destabilizing systems and terminating species. However, the Earth has recovered. Over and over, the Earth has returned to a succession of 'safe operating spaces'. Importantly, some disasters in the planets history have actually heralded new evolutionary trajectories. For example, the age of dinosaurs ended as a consequence of a likely combination of extraordinary planetary volcanism coupled with major asteroid/comet impact that triggered planetary-wide (climate) change. The end of the dinosaurs and many other species at the Cretaceous–Tertiary boundary approximately 65 million years ago (Kaiho et al. 2016; Petersen et al. 2016), opened up a space that ultimately led to the evolution of mammals and of course, *Homo sapiens*. There have been other significant evolutionary jumps and radiations of species after global catastrophes that would not have been possible without the opportunity and space created by those disasters (Goswami et al. 2016). As such, the contemporary crisis narrative of the Anthropocene that imagines the catastrophe of the Anthropocene as a unique event in the planet's history is materially inaccurate and demeans the hazard and disaster experience of the past. Furthermore, it is possible to imagine that the narrative of future disaster should not be viewed entirely in the negative and the 'disaster of the Anthropocene' may in fact be an important moment in the future history of the planet—one from which new species and systems evolve in which *Homo sapiens* do not play a major role.

Coupled to the last point, the contemporary language associated with the study of hazards, disasters, and disaster risk reduction is unhelpful, in my view, for thinking about and acknowledging that deeper history of planetary disasters. The contemporary use of the nomenclature of disaster risk reduction again gives preference to the present and the future over the past, framing past events as 'geological' or 'ecological' events rather than as the disasters they actually were to the species that inhabited the planet at the time (Albritton 1989). To understand this point, it is necessary to critically reflect on the definitions of the key concepts at the heart of the field of hazard, disaster, and disaster risk reduction. Whilst it is true that these terms are fluid and contested, internationally, academics and practitioners have settled on a collection of definitions that are broadly accepted and are provided by the UN through its office for Disaster Risk Reduction, the UNISDR (http://www.unisdr.org) in its official publication on disaster risk reduction terminology (available at: https://www.unisdr.org/we/inform/terminology). As the UNISDR says in the introduction to the global terminology

> "*The UNISDR Terminology aims to promote a common understanding and usage of disaster risk reduction concepts and to assist the disaster risk reduction efforts of authorities, practitioners and the public*" (UNISDR 2017).

To illustrate this point examination of the concepts of *hazard*, *disaster* and *resilience* should assist. According to the UNISDR, these terms are defined as follows:

> Hazard "*a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation*";

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

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

In respect of hazard, the focus is on the impacts and costs to humans and the things we directly value such as life, health, property, and economic activity. There is reference to the environment, but generally, this is in regard to environments and the goods and services they provide humans, rather than for the intrinsic value or right of environments and ecosystems for themselves. The point is the focus on us—*Homo sapiens*—to the exclusion of other, more-than-human entities. Hazards only seem to matter to humans—we are unconcerned with their impacts on the more-than-human, so the language has an almost entirely anthropocentric focus. Likewise, for the concept of disaster, the focus is on the negative disruption and effects to humans and the things we value and the associated inconvenience to us rather than upon the more-than-human and the wider collection of environments.

When critically reviewing the concept of resilience, whilst there is more explicit reference to the idea of environmental systems recovery as well as human system recovery [likely a consequence of the ecological systems origins of the concept (Alexander 2013)] the attention to 'timely efficiency' is again entirely anthropocentric in nature. *We* want things to recover quickly, so *we* can get back to normal as fast as possible. For humans with very short life spans, this is understandable. However, the planet has a longer life span and timely from the perspective of the planet and ecosystems (none of which are ever in a static state, because all systems are constantly changing), and the concept of recovery in a short, timely, and efficient manner is less meaningful. From a planetary perspective, recovery that takes a millennium or longer, such as the stabilization of the atmosphere after the cessation of human-induced carbon release, may take centuries to millennia (Rood 2014). But is that really a problem?

Disaster is a modern socially constructed concept (Wisner et al. 2014) placing the focus on people and the things we value and care about, and as such, it greatly diminishes the idea of disasters in deeper time. Hazardous events and the disasters they cause are not unique to the Anthropocene or of a uniquely anthropocentric nature, and the contemporary language negates that and reduces the significance of disaster impacts on natural ecosystems and environments of the planet through time and on the more-than-human. Denying the deeper experience of catastrophism that punctuates the story of the planet, denies the history of the planet, and robs us of lessons to be learned about the nature and consequences of hazards and disasters.

This leads us to the next question.

How do we give voice to the more-than-human experiences of Anthropocene disasters?

Explicit in the answer to the preceding question is that humans think about how the Anthropocene might do bad things to us via hazards and disasters. We give preference to ourselves, and our own needs. However, it is necessary we face the truth that we are in fact a serious hazard, or threat, or risk to other species and planetary ecosystems and our impact in the Anthropocene might mark a significant disaster in the history of the more-than-human. Some argue that the sixth great extinction event is now underway as a consequence of the actions of *Homo sapiens* across the planet (Barnosky et al. 2011). This sixth extinction will eventually be preserved within the geological record, meaning that humans will become synonymous with a significant ecological and ecosystem disaster within the planets history.

> *"what is clear is that extinction is part of the geological record; we are now…., in the sixth major episode in the planet's history. But it is a unique one caused by the actions of one species, a geological innovation of profound importance"* Dalby (2016:40)

Whilst experts—mostly from the fields of biology and ecology—have and are making contributions to this debate, scholars of hazard and disaster have been less attentive on the issue. Given the traditional focus by hazard and disaster scholars to concepts of equity, justice, and marginality underlying the vulnerability of humans to hazards and disasters, it seems appropriate that they bring their knowledge and skills to considering the idea that the more-than-human are experiencing injustice and a lack of equity in terms of the negative impacts of the Anthropocene on them. Malm and Hornborg (2014) argue that intra-species inequalities are unfortunately a part of the ecological crisis represented by the Anthropocene. However, do they need to be? Humanity—some of it anyway—is currently making decisions about which species to try and conserve and save from extinction whilst allowing others to disappear. Humans are actively 'marginalizing' some species over others. For example, iconic species such as polar or panda bears are easy to sympathize with. However, less attention is given to other species not so cuddly and cute. For example, no protests are held to protect the rights of, and to save bacteria, we cannot see or perhaps think are less worthy. Why do we try to give voice to some of the more-than-human but not others (Gibson-Graham 2011; Whitehouse 2015)? Why do we champion the needs and rights of some species but silence others? The decisions made now by some individuals with power and decision-making authority will have significant consequences for the planet and the more-than-human (Dalby 2016).

Is it possible to mitigate the impacts of future hazards and disasters within the Anthropocene without addressing the root causes of vulnerability?

Put simply, no. The narrative of the Anthropocene that imagines human ingenuity and capability will develop technological solutions that will reduce the vulnerability of the world's population to hazards and disasters verges on fantasy. This is because as noted by Dalby (2016:38, 40),

> "*The school of eco-pragmatism or ecomodernism equates affluent, technologically savvy Americans (privileged rich few in western countries) with humanity in general… and disregards the current condition and fate of the majority of humanity in the coming decades*", and, "*The techno-utopian vision of the future simply ignores the calamitous trajectory humanity is on, and, as such, is dangerously misleading*".

That is, detection, monitoring, observation, and early warning systems and technologies are not widely available to the most disadvantaged and vulnerable people. Therefore, losses from future disasters will not be mitigated, so again, only a few will benefit from this utopian vision of a good and opportunistic Anthropocene. Second and connected to this, rich, white, powerful interests in the west do not want the existing system driven by the wealth of a carbon economy to change. Malm and Hornborg (2014:64) observe:

> "*We would argue…. Uneven distribution is a condition for the very existence of modern fossil-fuel technology. The affluence of high-tech modernity cannot possibly be universalized—become an asset of the species—because it is predicated on a global division of labour that is geared precisely to abysmal price and wage differences between populations* (and making vulnerable the many—my emphasis)"

Studies of *vulnerability* emerged from the areas of food security and livelihoods and risk and natural hazards (see Fig. 3). Hazard and disaster scholars have been at the forefront of this work and have much to contribute in relation with the Anthropocene. Calgaro (2010) observes food security and livelihoods research explores the social–political, economic, and institutional conditions that influence food security, human welfare, livelihoods, and social differentiation. Vulnerability exists because of a lack of access and entitlement to resources or capital and is seen as a contextualized and politicized *social* condition moderated by poverty, inequality, unequal terms of trade, modes of production, power relations, and marginalization occurring at various scales of space and time. Environmental processes are important, but are less emphasized. Conversely, hazards work places emphasis on the physical environment. Vulnerability was traditionally viewed as a linear, negative outcome of a population's physical exposure to hazard, measured potential of impact and loss, and realized impacts of hazards (White 1973). As noted earlier, geophysical agents were the focus, prompting the development of technocratic solutions (Adger 2006; Calgaro 2010). The failure of technological solutions to reduce vulnerability triggered new research merging political economy and political ecology paradigms with the traditional physical sciences (Adger 2006; Burton et al. 1993). These approaches, epitomized by Wisner et al.'s (2004) Pressure and Release/Access to Resources Model, capture the physical conditions that heighten exposure, and the contextualized socio-political causal factors that create these conditions. Here, the natural hazard is seen as an independent trigger event that challenges the strength of the social–ecological system (Calgaro 2010; Pelling 2003; Wisner 1993).

More recent research on climate change draws on both traditions and has led to two basic framings (O'Brien et al. 2007). A scientific framing sees vulnerability as an outcome (IPCC 2001), whereas a human security framing views vulnerability as a contextualized characteristic, influenced by multidimensional interactions between biophysical, socio-political, economic, institutional, and technological conditions (O'Brien et al. 2007; Calgaro 2010). Thus, hazard and disaster scholars working at the intersections of the disciplines shown in Fig. 2 have much to offer.

Understanding the factors that reduce resilience and increase vulnerability within the coupled human–environment system, and their manifestation in particular places, has led to the development of integrated social and biophysical approaches within the interdisciplinary fields of sustainability science (Clark and Dickson 2003) and global environmental change. Emphasis on the coupled human–environment system acknowledges that humans are not detached from the physical world (Schröter et al. 2004; Calgaro 2010).

Ensuring the societal relevance of global environmental change research is important if transitions towards sustainability and improvements in human security are to be made within the Anthropocene (Moser 2010). Calgaro (2010) observes that the need for relevance has prompted O'Brien (2006) to propose a rethink in the way that global environmental change research is framed. Is scientific certainty and measurement of hazard events and change most important in supporting sustainability, or should societies goals be more aligned with reducing vulnerability and human insecurities (O'Brien 2006)? O'Brien (2006), Moser (2010) argue for a greater focus on the latter—a human security framing—over preoccupations with the scientific identification, measurement, and prediction practiced in physical science-based approaches that have failed to engage society in creating the transformations needed for sustainability—all the more important as we arrive at the Anthropocene. This aligns more with the security framing of Dalby (2017) referred to later. There are two advantages to this people-centred approach. First, it enables meaningful exploration into the role place-specific differences and personal circumstances play in producing differential vulnerability and resilience (Alexander 1997; Rigg et al. 2008). Second, this aids individuals and communities to respond effectively to change by challenging the drivers of vulnerability (O'Brien 2006).

As elegantly articulated by Calgaro (2010), vulnerability is place- and system-specific, contextualized, highly scaled, dynamic, and differential and a households or population's characteristics, the multiple stressors they face, and their capacity to respond and adapt, changes spatially and temporally. Vulnerability is determined by exposure, sensitivity, and system adaptiveness. Here, being vulnerable to a hazard not only means that the exposure unit is both exposed and sensitive to the effects, but must also exhibit limited ability to respond and adapt (Polsky et al. 2007). Exposure, sensitivity, and system adaptiveness are determined by unequal power and resource distributions that limit opportunities (Birkmann 2006). The more resources an individual, household, or community have, the lower the vulnerability (Moser 1998).

Another important determinant of vulnerability levels within communities is the mode of production operating, which influences rates and histories of development, capital concentration and governmental regulation over capital, and labour rights (Watts and Bohle 1993; Wisner 1978). Fundamental to this conceptualization of vulnerability, however, are the contested actions and outcomes that link human agency and scaled structures of power spatially and temporally. Here, political economies focus on social structures and economic systems as the key determinants of inequality is coupled with insights from constructivism that emphasizes the role human agency and culture play in producing differential vulnerability among individuals and groups (Calgaro 2010). Constructivists stress that human actors are causal agents in history and have the capacity to create and realize multiple possibilities within the context of current cultural contingencies (Emirbayer and Mische 1998). Vulnerability is generated through continuous interaction between social structures and human agency (Jessop 2005; Calgaro 2010).

Since power and political will plays a central role in creating and perpetuating vulnerability, efforts to reduce vulnerability to hazards and disasters in the Anthropocene will require destruction of existing power structures and economic systems. However, such changes are unlikely to be tolerated by existing elites (Calgaro 2010). As Dalby (2016) contends, many commentators fail to deal with the fact that social relations of power are at the heart of vulnerability, and consequently, how the Anthropocene is being shaped and experienced by the masses. Hazard and disaster scholars can, and must, bring attention to these issues.

Whilst the discussion has been focused principally on people, questions about the vulnerability of ecosystems, buildings, and urban environments are all equally relevant. Without dealing with the root causes of poor urban risk governance, inappropriate land use zoning, building code regulation and compliance, safety standards, post-construction operating regulations, and maintenance, our built environment will continue to remain sub-optimal, perpetuating the vulnerability of that built infrastructure and systems—and the people and the more-than-human species that occupy them (Acuto 2016; Birkmann et al. 2016). Consequently, hazard and disaster scholars with a focus on these areas have critical roles to play in changing the way we do business.

How do we make space for slow emergencies and what do slow emergencies mean for understanding hazard and disaster in the Anthropocene?

To date, hazard and disaster scholarship has been preoccupied mostly with the flare and glamour of rapid, sudden onset events. This is not entirely unexpected or unreasonable given the dramatic impacts that in particular, large-scale events such as the 2014–2016 Ebola outbreak in West Africa, the 1971 Bay of Bengal tropical cyclone disaster, the 2004 Indian Ocean tsunami, and the 2011 Japan earthquake–tsunami–nuclear events have on people and places. Modern classifications and analyses of hazards and disasters focus on what Rickards and Kearnes (2016) refer to as '"bounded events" that explode out of the assumed substrate of normal day-to-day life, triggering efforts to extinguish them as quickly as they appear'. This construct has in turn informed how some (many of us?) think about hazards and disasters in the Anthropocene, leading to a sense of what will the Anthropocene future hold in relation with the *sudden* occurrence of disaster? However, critical hazard and disaster scholarship should rupture this thinking. The "Anthropocene turn" demands that scholars consider the smooth background against which short-term fluctuations including emergencies, hazards, and disasters are manifest. We need to be attentive to the conditions that enable and facilitate apparent short-term, rapid onset events.

Critically, hazard and disaster scholars need to challenge the conceptual framings that define what we understand as emergencies and disasters, for those logics imply actions that either can, or cannot be. For Rickards and Kearnes (2016), there are two cultural logics of 'the accident' and 'the disaster'. In the story of the 'accident', emergencies occur when systems fail and things go wrong. In these circumstances, accidents occur when environmental and human systems of various kinds fail. Mitigative actions can presumably be imagined and actioned. Conversely, in the story of 'the disaster', ironically, disaster occurs as a consequence of how things go right—they are a consequence of industrial modernity. For example, the industrial revolution is a revolution of the consumption of fossil fuels, the consequence of which is anthropogenic climate change—attendant as it is with its extreme climate and weather events and disasters. Such alternative logics demand deep critical reflection for the Anthropocene, important as they are for the material living reality of the lives of the human and more-than-human masses. Furthermore, what do these cultural logics mean for the temporality of emergency and disaster now and in a future Anthropocene?

Whilst hazard and disaster scholars do think about and acknowledge slow onset disasters like drought and sea-level rise, the concept of the 'slow emergency' is something altogether more radical. Many processes might be reasonably imagined as *slow emergencies* including but not limited to climate change, the spread of antimicrobial resistance and desertification. The significances of the slow emergency are numerous. First, such processes and events lay the foundations from which rapid, sudden onset disasters emerge. For example, bushfires and floods are more common and intense in a world with a slowly changing climate and multi-drug-resistant epidemics and pandemics flare and kill in a world, where microbes have slowly become resistant to antimicrobial agents (Michael et al. 2014). Second, in being less attentive to slow emergencies, because they are traditionally not so visible and media worthy, we are tipping the risk scales towards larger rapid onset events that will erupt on spatial scales we find harder to respond too. Third, we will require different ways of monitoring and forecasting slow emergencies, and different conversations with societies about how to accommodate prepare for and respond to slow and fast onset disasters. These will also require compromises and discussions about what we value and what we are prepared to (not)accept now and for future generations, as well as, how to resolve issues of intergenerational justice and equity (Beck 1992). Fourth, when studying slow emergencies, we will require different types of data and knowledge. Traditional societies and knowledges may be more attentive than the currently privileged western sciences to recognizing the onset of slow emergencies, familiar as they are with subtle variations in seasonal, animal, and planet behaviours (Veland and Lynch 2016). Dalby (2016), Veland and Lynch (2016) passionately call for the voices, experiences, and knowledge of others, especially Aboriginal ones, to be heard. Last, and perhaps most importantly, the study of slow emergencies forces us to confront a simple truth which is that for the vast majority of human and more-than-human populations, the concept of 'the future hazard and disaster of the Anthropocene' is a fantasy. For them, they live their daily lives right now in a situation that may be characterized as *a slow- and continuing-emergency* (Rickards and Kearnes 2016; Veland et al. 2013).

Rickards and Kearnes (2016) correctly contend that for many, it seems that they are already living a never-ending succession of emergencies and crises. Malm and Hornborg (2014) go further and point out that the idea we all still exist in a "safe operating space" and that the Anthropocene is a future risk is nonsense for the growing proportion of the world's humans and more-than-human for which it is already a living disaster. For these, the coming Anthropocene disaster is already a *contemporary reality!* Confounding this disaster temporality, neoliberal policies and plans such as the Australian National Strategy for Disaster Resilience (Commonwealth of Australia 2011) eloquently detail how each of us needs to be personally responsible for our own resilience and disaster preparedness, yet at the same time, so many of us are disempowered by governments enacting restrictive legislation that confines possible future trajectories as a response to actual or perceived day-to-day security threats (Reid 2012). There is an unachievable gulf between the neoliberal rhetoric of resilience and the actual capacity of the masses. For many, the future is already bleak (IDMC 2015).

The consequence is that a process of perpetual 'emergency life' for too many has been normalized. If this position is accepted, what does this mean for hazards and disasters in the Anthropocene? Does the normalization of emergency life 'stretch the scales, meanings and timings of emergencies and disasters' and what does that imply for our capacity to anticipate and react to future Anthropocene disasters?

Different peoples, the more-than-human and places have experienced over and over the costs and consequences of the manifestations of emergencies, hazards and disaster that are the signature of the Anthropocene and its underlying drivers of imperialism and capitalism (Rickards and Kearnes 2016; Malm and Hornborg 2014). The consequences are both complex and frightening:

> *"... the sense that the planetary environmental crisis is 'over' and nature is already 'dead' is resisted by many scholars and activists as unbearably nihilistic and open to abuse by the very techno-optimists who caused the problem in the first place. But other critical scholars argue for positioning the Anthropocene disaster in the past rather than future in an effort to counter the implicit reification of the status quo contained within the idea that "we are all increasingly at risk (but are fine just now)", papering over the lived emergencies of many humans and more-than-humans that have long been politically sacrificed in the daily operations of industrial capitalism"*(Rickards and Kearnes (2016):3)

Hazard and disaster scholars from a broad sweep of disciplines listed in Fig. 2 must engage with the concept of the slow emergency that characterizes life for many in the Anthropocene. They must radicalize our understanding of sustained coping with emergency so as to identify new ways of knowing about the relationships between humans, the more-than-human and our environments in the face of a good or bad Anthropocene. Importantly, they must identify ways of surviving the coming threats. Critical questions to which such scholars might contribute include 'how can people be expected to be 'resilient' when so many are powerless?' and 'as citizens of disaster, do we effortlessly move (or are we violently thrown) between slow and fast emergencies and disasters operating at different scales of place and time?' Such critical work will help us think through:

> *"The conceptual challenge is also not to see these 'chronic stresses' as separate to the 'acute shocks' that resilience experts tell us we need to address. Seeing the linkages between the past, present and future and the patterns of ongoing privilege are essential if resilience is to be about more than housekeeping in preparation for future challenges"*(Rickards and Kearnes2016:6)

Does the scholarship of hazard and disaster provide evidence useful for informing the debate about an early or late-start for the Anthropocene?

Hamilton (2016) contends that,

> "*the Anthropocene cannot be defined merely by the broadening impact of people on the environment and natural world, which just extends what we have done for centuries or millennia*".

Rather, the Anthropocene is synonymous with our impact on the whole Earth system. Consequently, he suggests work to identify the start date of the Anthropocene is an academic folly.

The concept of landscape-wide ecology or even of archaeology as a whole measuring and identifying landscape impacts as markers of the commencement of the Anthropocene is not enough for Hamilton (2016). Hamilton (2016) argues that the consequence of the Anthropocene and, therefore, its date of origin are squarely laid at the foot of the industrialized use of carbon (a position that is highly valid) and, therefore, is indicative of a late-start, there ending the discussion. Oddly, though he decides, 1945 marks an appropriate start date for the Anthropocene. He further argues that other disciplines beyond Earth System Sciences have no role to play in the debate and that a late-start date for the Anthropocene is a must and an inevitability of the consequence of the use of carbon. However, contrasting strongly with Hamilton's perspective, Dalby (2016) observes:

> "*[many social and political scientists] are very concerned that the anthropocene discussion is being led by natural scientists and in the process the inequalities in human societies are occluded and politics replaced by an invocation of a universal singular humanity that has emerged from history by some 'natural' process*" (Dalby 2016:46).

In responding to the views of Hamilton (2016), Dalby (2016), there are two inter-related, but subtly conflated, points here. One is about the meaning and impact of the Anthropocene and the other is on the evidence to mark the start date. Clearly, hazard and disaster scholars with their attention to vulnerability, marginalization, injustice, inequality, differential power relations, and so on offer much to the social science debates about the meaning, impact, and response to the Anthropocene and on discussions about global and societal tolerances for different Anthropocene trajectories.

This sociological approach also feeds into how Hamilton and Grinevald (2015) consider the issue of the timing of the Anthropocene in another way, whereby they worry that the ideas of an early start (and good Anthropocene) denigrates the importance of the concept of the Anthropocene altogether. In the first instance, rather than there being a sharp rupture between the Holocene past and the Anthropocene now, a 'gradualized' transition making the Holocene and Anthropocene co-existent and one in which humanities impacts on the environment are spread across time obscures the horrifying nature of the Anthropocene and the extraordinary measures required to respond to its challenges.

If these lines of reasoning are accepted, then the start date for the Anthropocene is indeed 'late'. Consequently, hazard and disaster scholars can add evidence to the argument for a late-start, given they can contribute significant knowledge about the occurrence, distribution, impacts, effects, and records of distinctly Anthropocene hazards and disasters—that is, *atmospheric and hydrospheric carbon generated extreme events.* We are skilled at identifying evidence for floods, storms, heatwaves, bushfires, and other hazards within the historic and geological records. We have contributed to Earth System Sciences' efforts to demonstrate statistical changes in climate extremes—the hazards that trigger disasters—the consequence of the Anthropocene (Perkins-Kirkpatrick et al. 2016; Sewell et al. 2016). Given that the Anthropocene's arrival is commensurate with a marked increase in carbon and a destabilizing atmosphere and hydrosphere and consequently, more hazards and disasters—then hazard and disaster scholars are important experts in identifying traces of this evidence for Earth system change that point to a late-start.

In relation with the second subtle point embedded within the ideas advanced by Hamilton (2016), I respectfully disagree that discussion about the Anthropocene is the remit only of the Earth System Sciences in relation with the identification of evidence to pinpoint the start date of the Anthropocene and that discussion of earth surface impacts from other disciplines are irrelevant. In thinking about 'markers' to delineate the start of the Anthropocene, the footprints of human-induced hazards on the Earth surface are commensurate with humanities impact on the Earth system per se. Such markers provide an additional line of evidence that lends weight to an early start date. For example, the destabilization of hill slopes leading to landslides leading to river floods across damned and managed lakes and rivers in many locations or soil degradation due to landscape and farm management leading to landscape failure and reorganization (Anthony et al. 2014; Turner and Sabloff 2012). This presents a patch-work of evidence from a hazards and disasters perspective that enrich the picture used to think about the start date of the Anthropocene. That said, Earth scientists with their sedimentological commissions and international congresses are the internationally recognised authorities to summarize, debate, and agree the relevant physical evidence within the geological record to formalise a final, definitive statement.

Summary and concluding remarks

In the traditional hazards and disaster work, disasters are a social construct that preference humans over the more-than-human species and systems. Whilst necessary for (anthropocentric) disaster risk reduction efforts, such framings are inadequate for responding to the wider challenges of the Anthropocene. Discussion about, and acceptance of the idea of the Anthropocene forces us to reflect critically on humanities relationship with hazards and the disasters they may cause, but also on the disaster of humanity for the planet and the more-than-human. Hazard and disaster scholars are well placed to do this work, but need to begin to pay attention to the more-than-human.

Will the future Anthropocene be bad and if so for who? Current trajectories indicate that the majority of the human population and most more-than-human species will be negatively impacted. Thus, issues of who gets to shape the future and policies and practices of human development and their impacts on the Earth System matter enormously, and in many ways, this will be shaped by a privileged few—mostly in the west (Calgaro 2010; Dalby 2016). Dialogue about a possible good Anthropocene and a technological future capable of saving us from a bad Anthropocene must stop quickly, since such narratives deflect from the critical work needed that focuses on the structural disadvantage, marginalization and disempowerment and poverty of the world's masses (Klein 2014). Furthermore, since detection, monitoring, observation and early warning systems and technologies are not widely available to the peoples of the planet, losses from future disasters will not be mitigated, so again, only a few benefit from this utopian vision of a good and opportunistic Anthropocene.

Having considered all of these questions new work by Dalby (2017) on security is providing novel constructs around inter-coupled environmental–social insecurity that challenge ways of thinking about hazard and disaster in the Anthropocene. Dalby (2017) contends that humanity is remaking its environments generating new forms of insecurity, even though insecurity and disaster have journeyed with humanity throughout our history. Through a succession of theoretical debates from the 1960s onwards, discussion of climate insecurity has come to dominate ideas of environmental security and the provision of relatively safe conditions for routine human life. Dalby challenges us to recognize the interconnection between the Earth System and social formations, since these greatly affect environmental (in)security and by definition, hazards, and disasters. This is important, since it very much appears that feedback loops (in socio-ecological systems) are 'trapping' individuals, families, communities, and societies in repeating cycles of insecurity—products of inequitable processes.

In conclusion:

> *"what is clear from earth system science is that the geological conditions that humanity has known for all of recorded history are nearly over. What replaces them will be a world substantially remade by human actions. The consequent geopolitical question is whether contemporary civilization can quickly morph into something that simultaneously slows the rate of ecological change while effectively coping with the perturbations already set in motion"*(Dalby 2017)

In light of this, hazard and disaster histories cannot and must not be used to forecast or assess future risks and insecurities of the Anthropocene and we need new tools, methods, models, and data to understand future landscapes of disaster risk. Hazard and disaster scholars are well placed to assist in this effort.

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DDH conceived and wrote the manuscript. The author read and approved the final manuscript.

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