Title
Vulnerability in Climate Change Research: A Comprehensive Conceptual Framework

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1 Introduction

'Vulnerability' describes a central concept in a variety of research contexts. It has its roots in geography and natural hazards research but is now used by various research communities such as those dealing with disaster management, public health, development, secure livelihoods, and climate impact and adaptation. However, vulnerability is conceptualized in very different ways by these scientific communities. For instance, natural scientists tend to apply the term in a *descriptive* manner whereas social scientists tend to use it in the context of a specific *explanatory* model.

More than 20 years ago, Timmermann (1981) posited that *"vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern"*. Liverman (1990) noted that vulnerability *"has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk"*. I could easily add exposure, sensitivity, coping capacity, and criticality to this list. The existence of competing conceptualizations and terminologies of vulnerability has become particularly problematic in the context of anthropogenic climate change. The cross-cutting nature of the global climate problem requires the intense collaboration of scholars from different research traditions, such as climate science, disaster management, risk assessment, development, economics, and policy analysis. This collaboration must be based on a consistent terminology that facilitates researchers from different traditions to communicate clearly and transparently despite differences in the conceptual models applied (Laroui and van der Zwaan, 2001).

This paper assumes that there is no single 'correct' or 'best' conceptualization of vulnerability. Instead, the diversity of conceptualizations is seen primarily as a consequence of the term 'vulnerability' being used in different policy contexts, referring to different systems being exposed to different hazards. Nevertheless, a consistent framework and terminology is needed for interdisciplinary global change research. To illustrate the problem, let us consider a hypothetical question: *"Which of two regions is more vulnerable to climate change and variability: Florida or Tibet?"* Different researchers may reasonably provide different answers to this question. Many of them will suggest that Tibet is more vulnerable because it has less resources to cope with whatever threats climate change might bring about, it cannot depend on the national government to provide substantial assistance in the event of a disaster, it has less potential to diversify its income base, and it is already stressed by political conflict. Others might highlight Florida's vulnerability, emphasizing its low elevation that makes it highly susceptible to sea-level rise, its current exposure to hurricanes and the severe damages caused by them, and its current climate being already rather warm. Some researchers may refrain from providing an answer unless provided with detailed, preferably probabilistic, scenarios of regional climate change and sea-level rise. Still another group might argue that this question is not relevant at all, given the huge differences in climate, topography, and socioeconomic conditions between these two regions. Rather than siding with any one opinion, I argue that a meaningful consideration of this question depends on the context of the vulnerability assessment and requires a clear specification of the applied vulnerability concept. A similar argument has been brought forward by Luers et al. (2003).

In this paper, I present a comprehensive conceptual framework and terminology of vulnerability that facilitates the integration of the different research traditions involved in vulnerability and climate change research. This framework consists of three components. The first component is a terminology for describing the context of a vulnerability assessment in terms of the vulnerable system, the hazard of concern, the valued attributes of that system that are threatened by its exposure to this hazard, and a temporal reference. The second component is a scheme for classifying vulnerability factors according to two independent dimensions: scale and disciplinary domain. The third component is a terminology for describing any conceivable conceptualization of vulnerability based on the groups of vulnerability factors it comprises.

I want to emphasize from the outset that the vulnerability framework presented here are not meant to replace established terminologies or to introduce completely new terms. Instead, certain qualifiers are used to specify the vulnerability concept applied in a particular context in an effort to facilitate clarity and consistency in interdisciplinary communication. Scholars who are exclusively engaged in disciplinary vulnerability research are hoped to gain a broader view on vulnerability from the conceptual framework even though they might question its necessity. Researchers engaged in interdisciplinary vulnerability assessments are expected to find a valuable tool that helps them to assess the vulnerability literature and to communicate with colleagues from different research traditions.

Janssen et al. (2005) found 771 references to scientific articles that use the keyword ‘vulnerability’ in the context of global change research. Given the large body of literature already available on this subject, I do not intend to present an exhaustive review of the various schools of vulnerability research or of their historical development. For general reviews of the conceptualization of ‘vulnerability’, the reader is referred to Timmermann (1981), Liverman (1990), Cutter (1996), Kasperson and Kasperson (2001), UNEP (2002), Ford (2002), Turner II et al. (2003), Cardona (2003), and Prowse (2003). Publications focussing on the conceptualization of 'vulnerability' in climate change research include Adger (1999), Kelly and Adger (2000), Olmos (2001), Downing et al. (2001), Moss et al. (2001), Brooks (2003), Downing and Patwardhan (2003), and O'Brien et al. (2004a).

The remainder of this paper is organized as follows. Sect. 2 presents the conceptual framework of vulnerability and the associated terminology. Sect. 3 applies this framework to discuss the conceptualization of vulnerability in the main schools of vulnerability research and to review various earlier classifications of vulnerability, including the conceptual framework presented by Brooks (2003). Sect. 4 focusses on the conceptualization of vulnerability in the context of climate change. The main interpretations of vulnerability in climate change are briefly reviewed, implications of key characteristics of global climate change for the conceptualization of vulnerability are discussed, and this discussion is linked to the disputed definition of vulnerability from the IPCC Third Assessment Report. Sect. 5 concludes this paper.

2 Conceptual framework of vulnerability

The term 'vulnerability' is conceptualized in many different ways by scholars from different research communities, and even within the same research community. In this section, I develop a conceptual framework and a terminology of vulnerability that is generally applicable both within and outside the climate change context. Sect. 2.1 proposes a terminology of vulnerable *situations*, Sect. 2.2 presents a classification scheme for vulnerability *factors*, and Sect. 2.3 develops a comprehensive terminology of vulnerability *concepts*.

2.1 Terminology of vulnerable situations

Several authors have emphasized that the term 'vulnerability' can only be used meaningfully with reference to a particular vulnerable situation (*i.e.*, assessment context). Brooks (2003) suggests that one *"can only talk meaningfully about the vulnerability of a specified* system *to a specified* hazard *or range of hazards"*, and to distinguish between 'current' and 'future' vulnerability. Downing and Patwardhan (2003) present a formal nomenclature for the vulnerability of social systems that includes the *threat*, the *region*, the *sector*, the *population group*, the *consequence*, and the *time period*. Luers et al. (2003) *"argue that vulnerability assessments should shift away from attempting to quantify the vulnerability of a place and focus instead on assessing the vulnerability of selected variables of concern and to specific sets* *of stressors"*. Füssel (2004) describes climate-related vulnerability assessments based on the characteristics of the vulnerable *system*, the type and number of *stressors* and their *root causes*, their *effects* on the system, and the *time horizon* of the assessment.

All four frameworks specify (i) the *system* (or region and/or population group and/or sector) and (ii) the *hazards* (or threats or stressors) considered. Three of them also include (iii) the *consequences* (or effects or valued attributes or variables of concern), and (iv) a *temporal reference*. I use these four fundamental dimensions to describe the context of a vulnerable assessment.

System: The system or region and/or population group and/or sector of concern.

Considering that some research traditions do not restrict the concept of vulnerability to social systems, the three dimensions suggested by Downing and Patwardhan (2003) are combined into a single one that is applicable to natural systems as well.

Hazard: The external stressor (or set of stressors) of concern.

United Nations (2004) defines a 'hazard' broadly as *"a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation"*. Hence, a hazard is understood as some external influence that may adversely affect a valued attribute of a system.

Valued attribute: The valued attribute (or variables of concern) of the vulnerable system that are threatened by its exposure to the hazard.

Complex hazards, such as anthropogenic climate change or economic globalization, may have a wide range of effects on a particular system or community. Examples of valued attributes include human lives and health, the existence, income and cultural identity of a community, and the biodiversity, carbon sequestration potential and timber productivity of a forest ecosystem.

Temporal reference: The time period of interest.

If the vulnerability of a system or its exposure to the hazard is expected to change significantly during the time period considered in an assessment, statements about vulnerability should specify a temporal reference, *i.e.*, the point in time or period of time that they refer to. This is particularly relevant for vulnerability assessments addressing anthropogenic climate change, which may have a time horizon of several decades or longer.

These four attributes are universally applicable to a wide range of contexts and to different traditions of vulnerability research. I propose the following terminology to fully describe a vulnerable situation: *vulnerability of a system's valued attribute(s) to a hazard (in temporal reference)*. The temporal reference can alternatively be stated as the first qualifier. Examples for fully qualified descriptions of vulnerability based on this framework are "present vulnerability of smallholder agriculturalists in a specific region at risk of starvation to drought" (adapted from Downing and Patwardhan, 2003), "present vulnerability of a particular city's built infrastructure to hurricanes", "vulnerability of the income base of a particular ski resort to climate change over the next 30 years", and "vulnerability of a particular ecosystem's net primary production to wild-fires in 2050".

Let us review the Florida–Tibet example from Sect. 1 in the light of the discission above. The question posed there clearly specified the *system* (Florida and Tibet, respectively) and the *hazard* (climate change and variability), albeit rather vaguely. However, the question which of the two regions is more vulnerable could not be clearly answered because neither the *valued attributes* nor the *temporal reference* were specified. A vulnerability assessment focussing on human lives as the valued attribute, for instance, would probably consider Tibet as more vulnerable because the survival of nomads and subsistence farmers may be immediately threatened by extended droughts. An assessment focussing on economic impacts, in contrast, might consider Florida as more vulnerable, given the substantial concentration of capital along the coastline, which is threatened by storm surges, sea-level rise, and hurricanes. Regarding the temporal reference, an assessment focussing on current risks might regard Florida as more vulnerable to climate change and variability because it already suffers substantial damage from hurricanes at present. An assessment focussing on the late 21^{st}century, in contrast, might regard Tibet as more vulnerable since many Himalayan glaciers that are presently feeding the rivers of this arid region are expected to have disappeared by that time. In summary, the terminology presented here allows to clearly specify the reference of any statement about vulnerability (or closely related terms such as 'adaptive capacity' and 'risk').

2.2 Classification scheme for vulnerability factors

A clear description of the vulnerable *situation* is an important first step for avoiding misunderstandings around vulnerability. However, there are also different interpretations of the term 'vulnerability' itself (see Sect. 3.1). I propose to distinguish different vulnerability *concepts* by the vulnerability *factors* that they consider. (In the following discussion

I use the term 'vulnerability factor' in a rather broad sense. Readers who prefer to hold on to their established preferred conceptualization of 'vulnerability' might think of these factors as 'risk factors' instead of 'vulnerability factors'.)

I start this section with a brief review of existing conceptual frameworks of vulnerability. It turns out that none of these frameworks is comprehensive, and that the proposed terminologies are often incompatible with each other. I then present a two-dimensional classification scheme for vulnerability factors that consistently integrates the various frameworks suggested in the literature. In Sect. 2.3, I use this classification scheme as the basis for a comprehensive terminology of vulnerability concepts.

Various authors distinguish an 'external' and an 'internal' side of vulnerability to environmental hazards yet with different meanings associated to these two categories. Most authors use these terms to distinguish the external stressors that a system is exposed to from the internal factors that determine the effects on the system, respectively (*e.g.*, Chambers, 1989; Ellis, 2000; Sanchez-Rodriguez, 2002; Pielke Sr. and Bravo de Guenni, 2003). Others use them to distinguish 'external' structural socioeconomic factors as investigated by human ecology, political economy, and entitlement theory from 'internal' agency-oriented factors as investigated in access to assets models, crisis and conflict theory, and action theory approaches (*e.g.*, Bohle, 2001).

United Nations (2004) distinguish four groups of vulnerability factors that are relevant in the context of disaster reduction: *physical* factors, which describe the exposure of vulnerable elements within a region; *economic* factors, which describe the economic resources of individuals, populations groups, and communities; *social* factors, which describe non-economic factors that determine the well-being of individuals, populations groups, and communities, such as the level of education, security, access to basic human rights, and good governance; and *environmental* factors, which describe the state of the environment within a region. All of these factors describe properties of the vulnerable system or community rather than of the external stressors.

Moss et al. (2001) identify three dimensions of vulnerability to climate change. The *physical-environmental* dimension *"accounts for the harm caused by climate"*. It refers to the climatic conditions in a region and to the biophysical impacts of climate change, such as changes in agricultural productivity or the distribution of disease vectors. The *socioeconomic* dimension refers to *"a region's capacity to recover from extreme events and adapt to change over the longer term"*. The third dimension, *external assistance*, is defined as *"the degree to which a region may be assisted in its attempts to adapt to change through its allies and trading partners, diasporic* *communities in other regions, and international arrangements to provide aid"*. In contrast to United Nations (2004), this conceptualization of vulnerability includes factors outside the vulnerable system, such as characteristics of the stressor and the expected level of external assistance.

Several researchers distinguish biophysical (or natural) vulnerability from social (or socioeconomic) vulnerability. However, there is no agreement on the meaning of these terms. The conceptual framework for coastal vulnerability assessment developed by Klein and Nicholls (1999) sees 'natural vulnerability' as one of the determinants of 'socioeconomic vulnerability'. Cutter (1996), in contrast, regards the 'biophysical' and the 'social' dimension of vulnerability as independent. According to the terminology proposed by Brooks (2003), finally, *"social vulnerability may be viewed as one of the determinants of biophysical vulnerability"*.

Each of the terminologies cited above provides an important distinction of the factors that may be relevant for assessing the vulnerability of a system to a specific hazard. However, these terminologies are clearly incompatible with each other, and none of them allows to consistently integrate the others. The main reason for this confusion is the failure to distinguish between two largely independent dimensions of vulnerability (or risk) factors, *scale* and *disciplinary domain*, which are defined as follows.

Scale: Internal *vs.* external

> Internal vulnerability factors refer to characteristics of the vulnerable system or community itself. Vulnerability factors that can be controlled by the considered community, such as the land use within their jurisdiction, are also considered internal. All other vulnerability factors are denoted as external. The designation of a particular factor as internal or external may depend on the scope of the vulnerability assessment. National policies, for instance, would be regarded as internal in a national assessment but as external in an assessment at the communal level.

Disciplinary domain: Socioeconomic *vs.* biophysical

> Socioeconomic vulnerability factors are those that relate to economic resources, the distribution of power, social institutions, cultural practices, and other characteristics of social groups typically investigated by the social sciences and the humanities. Biophysical vulnerability factors, in contrast, are related to system properties investigated by the physical sciences. These two categories may sometimes overlap, for instance in the case of built infrastructure.

I argue that the dimensions 'scale' and 'disciplinary domain' are largely independent and therefore should be considered separately. Ta-

Domain / Scale	Socioeconomic	Biophysical
Internal	**Response capacity** *e.g.*, household income, social networks, access to information	**Sensitivity** *e.g.*, topography, environmental conditions, current climate
External	**"External social factors"** *e.g.*, national policies, international aid, economic globalization	**Exposure** *e.g.*, severe storms, earthquakes, sea-level change

Table 1: Classification of vulnerability factors according to scale and disciplinary domain (see text)

ble 1 illustrates the independence of these dimensions by providing examples for the four categories of vulnerability (or risk) factors implicitly defined by them. Each category is shown with a synonymous term commonly used in the vulnerability literature if such a term exists. My intention is not to replace these established terms, which are extremely useful in a context where there meaning is clear. The purpose of the 'systematic' terms presented here is to allow the consistent description of any vulnerability concept from the literature without having to recur to the terminology of a particular school of vulnerability research.

Let us now illustrate the four groups of vulnerability factors by applying them to the Florida–Tibet example presented in Sect. 1. A crude analysis would suggest that Tibet is more vulnerable in terms of internal socioeconomic factors (response capacity; *e.g.*, average household income) and external socioeconomic factors (*e.g.*, national economic policies). In contrast, Florida may be more vulnerable in terms of internal biophysical factors (sensitivity; *e.g.*, coastal topography) and external biophysical factors (exposure; *e.g.*, tropical storms). The difficulty in answering the question *"Which region is more vulnerable to climate change and variability?"* thus originates from the lack of specification what we are actually interested in, *i.e.*, which hazards, valued attributes, and vulnerability factors should be considered, and how these factors should be weighted.

The classification scheme for vulnerability factors presented in Table 1 constitutes the *minimal* structure for describing the multitude of vulnerability concepts from the literature. Taken together, the four groups of vulnerability factors constitute the vulnerability profile of a particular system or community to a specific hazard at a given point in time. Each of these groups of factors can be broken down further in order to more accurately describe the factors that are relevant in a specific assessment context. Internal social vulnerability factors, for instance, may be further distinguished between generic factors and factors that are specific for the particular hazard considered (Brooks, 2003).

While vulnerability can principally be reduced by targeting any group of vulnerability factors, not all vulnerability factors are amenable to policy interventions in all situations. Classical hazards assessments, for instance, have regarded 'natural' hazards as exogenous to the vulnerability assessment. This view, however, no longer holds in the context of climate change assessments, which are concerned exactly with changes in the frequency and magnitude of climatic hazards expected as a result of anthropogenic greenhouse gas emissions. The conceptualization of vulnerability in a particular assessment context tends to include those vulnerability factors that are seen as targets for policy interventions (see Sect. 4.1). I want to emphasize explicitly that I am in no way suggesting that vulnerability assessments that consider only on a subset of the four factor groups are incomplete.

2.3 Terminology of vulnerability concepts

Different interpretations of vulnerability can be distinguished based on which of the four groups of vulnerability factors are included. I propose the following terminology to denote different vulnerability definitions. Vulnerability definitions comprising only *one* group of factors are denoted by adding the scale and the domain as qualifiers (*e.g.*, 'internal socioeconomic vulnerability'). All relevant vulnerability definitions that comprise factors from *two* groups combine factors from either the same scale or the same domain. The qualifier 'cross-scale' is used for combinations of internal and external factors, and 'integrated' for combinations of socioeconomic and biophysical factors. These qualifiers allow to uniquely denote vulnerability definitions combining two groups of factors (*e.g.*, 'cross-scale socioeconomic vulnerability') or all *four* groups ('cross-scale integrated vulnerability'). The pertinent literature contains two vulnerability definitions that combine *three* groups of factors (see Sect. 3.2). In the absence of a simpler qualifier that is both handy and clear, these are denoted as 'cross-scale socioeconomic vulnerability *cum* sensitivity' and 'internal integrated vulnerability *cum* exposure'. This terminology allows to consistently characterize any vulnerability concept.

One limitation of the terminology of vulnerability concepts described so far is its indifference with respect to time. The 'response capacity' of a community to climate change, for instance, comprises its 'coping capacity' (*i.e.*, its ability to cope with short-term weather variations) as well as its 'adaptive capacity' (*i.e.*, its ability to adapt to long-term climate change), which may be determined by different factors. Discussions about vulnerability concepts that do not refer to a particular vulnerable situation (as described in Sect. 2.1) may thus have to specify explicitly the temporal reference of the vulnerability concepts in addition to their domain and scale. I propose to use the terms 'current', 'future', and 'long-term' for this purpose, depending on whether the vulnerability concept refers to the present, to the future, or to the present *and* the future, respectively. Hence, 'coping capacity' refers to 'current internal socioeconomic vulnerability factors', and 'adaptive capacity' refers to 'long-term internal socioeconomic vulnerability factors'.

The combination of the terminology of vulnerable situations from Sect. 2.1 and the terminology of vulnerability concepts presented here represents a comprehensive conceptual framework of vulnerability, spanned by the following six dimensions:

- **Temporal reference**: current *vs.* future *vs.* long-term
- **Scale**: internal *vs.* external *vs.* cross-scale
- **Disciplinary domain**: socioeconomic *vs.* biophysical *vs.* integrated
- **Vulnerable system**
- **Valued attribute**
- **Hazard**

An example for a fully qualified characterization of vulnerability according to this framework is 'current internal socioeconomic vulnerability of the livelihood of Tibetan subsistence farmers to drought'. Obviously, statements about vulnerability involving all six dimensions are rather unhandy. In practice, one will only specify those attributes that are not clear from the context. The Florida–Tibet example has shown, however, that each dimension may be relevant for avoiding misunderstandings what is meant by 'vulnerability' in a particular context.

The conceptual framework of vulnerability presented here can be applied in various ways. First of all, it allows to communicate clearly which interpretation of vulnerability is used in a specific assessment. Second, it facilitates the discussion how and why different vulnerability concepts differ from each other. Third, it provides a framework for reviewing existing terminologies of vulnerability. Examples for all these applications will be provided in the remainder of this paper.

Approach	Vuln. factors				Denotation
	IS	IB	ES	EB	
Risk-hazard	–	X	–	–	Internal biophysical vuln.
Social constructivist	X	–	?	–	Cross-scale socioeconomic vuln.
Hazard-of-place	X	X	?	X	Cross-scale integrated vuln.

Table 2: Correspondence between the conceptualization of vulnerability according to three major approaches of vulnerability research (left-most column), the vulnerability factors included (central columns), and the denotation according to the terminology presented in Sect. 2.3 (right-most column). Abbreviations: IS=internal socioeconomic; IB=internal biophysical; ES=external socioeconomic; EB=external biophysical. A question mark denotes that the respective vulnerability factor may or may not be included in the respective conceptualization of risk.

3 Application of the conceptual framework

This section presents several applications of the conceptual framework of vulnerability developed in Sect. 2. Sect. 3.1 characterizes the conceptualization of vulnerability in the classical approaches to vulnerability research, Sect. 3.2 reviews earlier vulnerability frameworks, and Sect. 3.3 discusses the conceptual framework of vulnerability proposed by Brooks (2003).

3.1 Classical approaches to vulnerability research

There are three major frameworks for vulnerability research. Table 2 presents these frameworks and indicates which of the four groups of vulnerability factors distinguished in Sect. 2.2 are typically included in the respective conceptualization of vulnerability.

Risk-hazard framework

The risk-hazard framework is applied to assess the risks to certain valued elements ('exposure units') that arise from their exposure to specific hazards. Similar to 'vulnerability', the term 'risk' is also interpreted in different ways (see, *e.g.*, Coburn et al., 1994; Adams, 1995; Cardona, 2003; Kelman, 2003). The use of the term in this paper always refers to the concept denoted as 'outcome risk' by Sarewitz et al. (2003). A general definition for '(outcome) risk' is *"expected losses [. . .] resulting from inter-*

actions between natural or human-induced hazards and vulnerable conditions" (United Nations, 2004).

The risk-hazard framework distinguishes two factors that determine the risk to a particular system: the 'hazard', which is *"a potentially damaging physical event, phenomenon or human activity [that] is characterized by its location, intensity, frequency and probability"*, and the 'vulnerability', which denotes the *"relationship between the severity of hazard and the degree of damage caused"* (UN DHA, 1993; Coburn et al., 1994; United Nations, 2004). The vulnerability relationship is variably denoted as 'hazard-loss relationship' in natural hazards research, 'dose-response relationship' or 'exposure-effect relationship' in epidemiology, and 'damage function' in macroeconomics.

The risk-hazard approach is most widely applied in the technical literature on disasters. It generally assumes that hazard events are rare, and that the hazard is known and stationary (*i.e.*, the underlying process does not change over time). The respective vulnerability definition refers primarily to physical systems, including built infrastructure, and it is descriptive rather than explanatory. Applying the terminology from Sect. 2, this vulnerability concept is characterized as 'internal biophysical vulnerability'. The terms 'sensitivity' and 'susceptibility' are also used to denote this concept.

Social constructivist framework

The social constructivist framework is applied to analyze who is most vulnerable, and why. According to this framework, vulnerability denotes the socioeconomic response capacity of individuals and groups to a variety of stressors. With a focus on natural hazards, Dow (1992) defines vulnerability as *"the differential capacity of groups and individuals to deal with hazards, based on their positions within physical and social worlds"*, and Blaikie et al. (1994) as *"the capacity of a person or group to anticipate, cope with, resist, and recover from the impact of a natural hazard"*. With a broader focus, Adger and Kelly (1999) characterize vulnerability as *"the state of individuals, groups or communities in terms of their ability to cope with and adapt to any external stress placed on their livelihoods and well-being. [...] It is determined by the availability of resources and, crucially, by the entitlement of individuals and groups to call on these resources."*

The social constructivist framework, which is rooted primarily in political economy, prevails in the poverty and development literature. Its vulnerability definition refers exclusively to people, and it is based on an explanatory model of socioeconomic vulnerability to a range of stresses and consequences. Applying the terminology from Sect. 2, this vulnerability concept is characterized as 'internal social vulnerability' or 'cross-scale social vulnerability'. The terms 'response capacity', 'coping capacity', and 'resilience' are also used to denote this concept.

Hazard-of-place framework

The risk-hazard framework and the social constructivist framework represent the classical traditions for conceptualizing vulnerability in the natural and engineering sciences and the social sciences, respectively. They largely correspond to the 'geocentric' and 'anthropocentric' approaches to the study of criticality identified by Kasperson et al. (1995), and to the 'direct' and 'adjoint' approaches to assessing climate impacts distinguished by Parry et al. (1988). The two traditions have been combined in various integrated frameworks, most notably the hazard-of-place framework proposed by Cutter (1996).

Integrated definitions of vulnerability combine characteristics of a vulnerable social unit with its exposure to external (biophysical) stressors. Cutter (1993) defines 'vulnerability' as *"the likelihood that an individual or group will be exposed to and adversely affected by a hazard. It is the interaction of the hazards of place [...] with the social profile of communities."* In the context of health risks from extreme weather events, 'vulnerability' was defined by the National Research Council (2001) as the *"extent to which a population is liable to be harmed by a hazard event. Depends on the populations's exposure to the hazard and its capacity to adapt or otherwise mitigate adverse impacts."* In the context of food insecurity, the World Food Programme (2004) *"sees vulnerability as being composed of two principal components, namely: i) risk of exposure to different types of shocks or disaster event. [...] ii) ability of the population to cope with different types of shock or disaster event."*

Integrated definitions of vulnerability are widely used in the context of global change and climate change (see Sect. 4), referring to regions, communities, or other social units. An important application is in vulnerability (or risk) mapping, which is a multidisciplinary approach using GIS techniques for identifying particularly vulnerable (or critical) regions (see, *e.g.*, O'Brien et al., 2004b). Assessments have traditionally focussed on physical stressors, such as natural hazards or climate change. Some recent efforts however, such as the 'double exposure' project (O'Brien and Leichenko, 2000; O'Brien et al., 2004b), have assessed the combined effects of biophysical and socioeconomic stressors.

Other conceptualizations of vulnerability

Some authors have used the term 'vulnerability' largely synonymous to 'exposure' or 'risk of exposure'. Examples include *"Human vulnerability* *to severe storms continues to rise because of the progressive occupation of hazardous areas"* (Smith, 1996, p. 210) and *"An estimated 75 million people [in Bangladesh] are vulnerable to arsenic poisoning"* (UNEP, 2002, p. viii). Since this interpretation is not reflected in a formal definition of vulnerability, I have not included it in Table 2.

3.2 A second view on classifications of vulnerability

In this section, the vulnerability framework from Sect. 2 is applied to take a second view on vulnerability classifications from the literature, and to investigate the reasons for their inconsistencies.

Table 3 analyzes important vulnerability concepts according to the vulnerability factors that they include. The most interesting observations are as follows:

- In total, eight different vulnerability concepts can be distinguished (1–8).
- The qualifier 'social' / 'socioeconomic' is used for four different concepts (1, 4, 6, 8).
- The qualifier 'biophysical' / 'natural' is used for three different concepts (5, 6, 7).
- The qualifiers 'socioeconomic' as well as 'biophysical' are used to denote 'cross-scale integrated vulnerability' (6).
- Some classification schemes are exclusive (*i.e.*, a particular vulnerability factor never occurs in more than one of the categories), whereas others are inclusive (*i.e.*, one category includes all vulnerability factors covered by the other category).
- It is not always clear whether 'external socioeconomic factors' are included in a particular concept or not.

Obviously, none of the one-dimensional classification schemes cited in Table 3 is able to consistently and comprehensively distinguish the four fundamental components of vulnerability identified in Table 1, let alone the eight vulnerability concepts shown in Table 3. This observation reinforces that the more complex conceptual framework presented in Sect. 2 is necessary for clearly characterizing all vulnerability concept found in the literature.

Classification scheme	V. factors IS	IB	ES	EB	Denotation (v.=vulnerability)	No.
Bohle (2001)						
Internal	X	–	–	–	Internal socioecon. v.	1
External	–	–	X	–	External socioecon. v.	2
Sanchez-Rodriguez (2002)						
Internal	X	–	–	–	Internal socioecon. v.	1
External	–	–	–	X	External biophys. v.	3
Cutter (1996)						
Social	X	–	X	–	Cross-scale socioecon. v.	4
Biophysical	–	X	–	X	Cross-scale biophys. v.	5
Klein and Nicholls (1999)						
Socioeconomic	X	X	?	X	Cross-scale integr. v.	6
Natural	–	X	–	–	Internal biophys. v.	7
Moss et al. (2001)						
Socioeconomic	X	–	–	–	Internal socioecon. v.	1
"External assistance"	–	–	X	–	External socioecon. v.	2
Physical-environm.	–	X	–	X	Cross-scale biophys. v.	5
Brooks (2003)						
Social	X	X	?	–	Cross-scale socioecon. v. *cum* sensitivity	8
Biophysical	X	X	?	X	Cross-scale integr. v.	6
United Nations (2004)						
Social & economic	X	–	–	–	Internal socioecon. v.	1
Physical & environm.	–	X	–	–	Internal biophys. v.	7

Table 3: Correspondence between the vulnerability concepts distinguished in major classification schemes from the literature (left-most column), the vulnerability factors covered by the respective concept (central columns), and the denotation according to the terminology presented in Sect. 2.3 (second right-most column). The right-most column numbers the different vulnerability concepts. See the legend of Table 2 for further explanations.

3.3 Criticism of Brooks' vulnerability framework

Noting the considerable confusion about the meaning(s) of the term 'vulnerability', in particular in the climate change context, Brooks (2003) intends *"to present a tentative conceptual framework for studies of vulnerability and adaptation to climate variability and change, generally applicable to a wide range of contexts, systems and hazards. [...] The IPCC definition of vulnerability is discussed within this concept, which helps us to reconcile apparently contradictory definitions of vulnerability"*. I will review these claims in this section. The reasons for doing this are, first, to motivate the need for the framework presented here, and second, to clarify some of the more common misconceptions encountered in Brooks (2003).

The core of the framework suggested in Brooks (2003) is the distinction between two interpretations of vulnerability in climate change research, which are denoted as 'social vulnerability' and 'biophysical vulnerability'. According to this distinction, *"social vulnerability [...] describe[s] all the factors that determine the outcome of a hazard event of a given nature and severity"* whereas *"biophysical vulnerability [is] a function of hazard, exposure, and sensitivity"* that *"has much in common with the concept of risk as elaborated in the natural hazards literature"*. Hence, the main difference between these two concepts is that social vulnerability does not include characteristics of the hazard.

In the remainder of this section, I will cite and critically discuss selected statements from Brooks (2003), which I consider to be misleading. The discussion is structured according to the misconceptions underlying these statements.

Misleading use of established terms

> *"The confusion arising from different usages of the term 'vulnerability' may be largely overcome by differentiating between 'social vulnerability' and 'biophysical vulnerability', terms that are already commonly used by some members of the research community." (Brooks, 2003, p. 2)*

While it is correct that these two terms are already used in the research community, Table 3 shows that they are used quite inconsistently. Brooks (2003) adds yet another interpretation for each of these terms, thus increasing rather than decreasing the confusion around their meaning.

> *"The term 'social vulnerability' is used in a broad sense to describe all the factors that determine the outcome of a hazard event of a given nature and severity. [...] Social vulnerability therefore en-*

compasses elements of the physical environment, [...] including factors such as topography." (p. 5)

The inclusion of physical factors such as topography into the concept of 'social vulnerability' is counterintuitive and thus likely to increase rather than decrease the confusion around these terms.

"Hence social vulnerability may be viewed as one of the determinants of biophysical vulnerability." (p. 4)

As discussed in Sect. 3.2, other scholars regard the 'biophysical' and the 'social' dimension of vulnerability as independent, or they see 'natural vulnerability' as one of the determinants of 'socioeconomic vulnerability'.

Failure to distinguish between 'hazard' and 'exposure to hazard' in multi-scale assessments

"This contradiction [between two vulnerability definitions] further illustrates the principal disagreement over the definition of vulnerability within the climate change research community, namely whether vulnerability is determined purely by the internal characteristics of the system, or whether it also depends on the likelihood that a system will encounter a particular hazard." (p. 6)

The "principal disagreement" noted but not explained by Brooks (2003) arises from the fact that different research traditions within the climate change community apply the vulnerability concept to hazards at different scales. As I argue in more detail in Sect. 4.2, vulnerability assessments concerning global, spatially heterogeneous hazards require 'downscaling information' (also denoted as 'regional exposure factor') for determining the expected exposure of a particular system (on the regional or local scale) for a given magnitude of the hazard (on the global scale). Specifically, assessments of 'vulnerability *to global climate change*' need to consider the spatial pattern of anthropogenic climate change, which is not *"determined purely by the internal characteristics of the system"*. The vulnerability relationship for a more localized hazard, such as wind storms, in contrast, can be determined without reference to detailed information about the hazard. The confusion apparent in Brooks (2003) reemphasizes the importance of talking about vulnerability *to a specific hazard*, as demanded by the terminology presented in Sect. 2.1.

Failure to distinguish between discrete and continuous hazards

"The principal difference between the natural hazards risk-based approach and the IPCC biophysical vulnerability approach is that

risk is generally described in terms of probability, whereas the IPCC and the climate change community in general tend to describe (bio-physical) vulnerability simply as a function of certain variables." (p. 7)

This statement suggests a "principal difference" between the risk–hazards approach and the IPCC approach to climate impact assessment without providing a convincing reason. In fact, both approaches can be brought in agreement once differences in the hazard between the two approaches are accounted for.

The most general definition of '(outcome) risk' is *"expected losses [...] due to a particular hazard for a given area and reference period"* (Adams, 1995). Hence, risk is a function of the hazard (including the likelihood and/or frequency of hazards of a particular magnitude), the exposure of the system to the hazard, and the internal vulnerability of the system. Two simplifications are often made. First, in the case of rare discrete hazards of a given magnitude, risk can be described as the probability of hazard occurrence times the consequences of exposure to the hazard, or shortly: Risk = Probability * Consequences. Second, in the case of a linear relationship between hazard and consequences, risk equals the expected magnitude of the hazard times the vulnerability to this hazard, or shortly: Risk = Hazards * Vulnerability. It is important to note that both simplifications are just special cases of the more general concept of risk denoting 'expected losses'.

The cited statement refers to the first simplification, which assumes a discrete hazard. In the climate change context, this simplification (and the associated conceptualization of 'risk' as 'probability times consequences') is applicable to uncertain discrete climate events, such as a potential breakdown of the North Atlantic thermohaline circulation. Impact assessments of smooth climate change, in contrast, need to apply the more general definition of risk as 'expected losses'. This can be done by assessing the consequences for a range of plausible regional climate scenarios, and weighting the results with the relative likelihood of the underlying climate scenario.

Erroneous conceptualization of vulnerability and risk in the risk-hazards framework

"The hazards and impacts approach typically views the vulnerability of a human system as [...] a function of hazard, exposure and sensitivity. [...] Biophysical vulnerability [...] is broadly equivalent to the natural hazards concept of risk." (p. 4)

According to the risk-hazard approach, 'hazard' and 'vulnerability' are the two fundamental and *independent* determinants of 'risk' (*cf.* Sect. 3.1). 'Risk' differs from 'vulnerability' in that it is contingent on the hazard. By wrongly characterizing 'hazard' as a determinant of 'vulnerability' and equating 'risk' with (biophysical) 'vulnerability', Brooks (2003) further adds to the confusion about these terms rather than reducing it.

The IPCC definition of vulnerability to global climate change (McCarthy et al., 2001, *cf.* Sect. 4.2) is often interpreted as being equivalent to the concept of risk in the risk-hazard approach. A consistent interpretation of this vulnerability definition, however, requires to understand it as denoting the level of risk *for a given level of global climate change*. Consequently, the risk (*i.e.*, expected impacts) to a system or community is determined by the magnitude of the hazard 'global climate change' as well as the vulnerability of the system to that hazard (according to the IPCC definition).

Summary

The above examples show that the framework presented in Brooks (2003) falls short of resolving the widespread confusion around 'vulnerability' and related terms. One of the major flaws is the distinction of only two interpretations of vulnerability, denoted as biophysical and social vulnerability. Ironically, the importance of the second dimension of vulnerability factors identified in Sect. 2.2, scale, is acknowledged by Brooks (2003) in the context of adaptive capacity: *"Are we defining adaptive capacity at the system and sub-system level only, or does our definition include the 'exogenous' factors that facilitate or inhibit the realisation of sub-system capacity?"* It is not clear why Brooks (2003) does not apply this distinction between internal and exogenous factors to vulnerability as well.

4 Vulnerability to climate change

Anthropogenic climate change differs substantially from other concerns to which vulnerability assessments have been applied, with important implications for the design of vulnerability assessments and for the definition of key concepts. This section focusses on the conceptualization of vulnerability in climate change research. Sect. 4.1 reviews the two main interpretations of vulnerability in climate change research. Sect. 4.2 discusses how the vulnerability concept employed by the risk-hazard framework needs to be modified in the context of global climate change, and links this discussion to the debated vulnerability definition in the IPCC Third Assessment Report.

4.1 Two interpretations of vulnerability in climate change research

In this section, I sketch how the two main interpretations of vulnerability in climate change research have developed in response to the diverse information needs of policymakers concerned with global climate change. The two fundamental options for limiting the adverse impacts of anthropogenic climate change are *mitigation* of climate change, which refers to confining global climate change by reducing the emissions of greenhouse gases or enhancing their sinks, and *adaptation* to climate change, which moderates the adverse effects of climate change through a wide range of actions that are targeted at the vulnerable system or population. A third response option, which has attracted limited scientific and policy interest so far is *compensation* for climate change, typically conceived as transfer payments (or other assistance) from those countries who disproportionately contributed to climate change to those who disproportionately suffer from it (*e.g.,* Paavola and Adger, 2002).

All three response options of climate policy rely on information about the vulnerability of key systems to climate change. However, their specific information needs differ significantly, for instance with regard to the relevant time horizon and the importance of distinguishing the impacts of anthropogenic climate change from those of natural climate variability. The three main traditions of vulnerability research (*cf.* Sect. 3.1) vary in their ability to provide information for the three response options. The risk-hazard framework can, in principle, provide important information for mitigation policy but it needs to be substantially extended to reflect the specific characteristics of the hazard 'global climate change' (see Sect. 4.2 for a more detailed discussion). The social constructivist framework can provide important information for the design of adaptation policies, in particular in developing countries. However, it also needs to be adapted to account for the unique challenges associated with long-term climate change. Integrated frameworks, as the most general category, are capable of providing information for all climate policy options, including compensation.

Reviews of the interpretations of 'vulnerability' in climate change research have generally identified two different vulnerability concepts. O'Brien et al. (2004a) distinguish between an 'end-point' and a 'starting-point' interpretation of vulnerability. In a nutshell, vulnerability according to the end-point interpretation represents the net impacts of climate change (for a given level of global climate change), taking into account feasible adaptations. This interpretation is consistent with the integrated framework of vulnerability research. It is most relevant for the development of mitigation policy and for the prioritization of international assistance. Vulnerability according to the starting-point interpretation assumes that addressing (internal socioeconomic) vulnerability to current climate variability will also reduce vulnerability to future climate change. This interpretation is largely consistent with the social constructivist framework and addresses primarily the needs of adaptation policy. The two types of vulnerability research underlying these interpretations of vulnerability correspond well with the two types of adaptation research distinguished by Smit et al. (1999) and by Burton et al. (2002).

Table 4 summarizes the main differences between the two interpretations of vulnerability in climate change research. For a more detailed discussion of these two frameworks, and for examples of studies applying them, the reader is referred to O'Brien et al. (2004a).

4.2 The IPCC definition of vulnerability to climate change

The aim of this section is to develop a consistent definition of 'future (or long-term) vulnerability to global climate change', using the risk-hazard framework as a starting point. I will first discuss how the characteristics of the hazard 'global climate change' affect the conceptualization of 'vulnerability' employed in the risk-hazard framework. I will then link this discussion to the contended vulnerability definition from the glossary of the IPCC Third Assessment Report (McCarthy et al., 2001).

The risk-hazard framework has been widely applied in risk assessments to estimate the expected damages caused by different kinds of hazards, including climatic hazards. Standard applications of disaster risk assessment (DRA) are *"primarily concerned with short-term (discrete) natural hazards, assuming known hazards and present (fixed) vulnerability"* (Downing et al., 1999). Key characteristics of the climate change problem, in contrast, are that it is long-term, it is global but not uniform, it involves multiple climatic hazards, it may have diverse effects on a system, it is associated with large uncertainties about future hazard levels, and it is attributable to human action. In a nutshell, the hazard and risk events considered in DRA are limited in time and space, whereas the global climate change is not.

Table 5 summarizes the main differences between classical risk assessments addressing natural hazards and vulnerability assessments addressing global climate change. These differences have important impli-

	End-point interpretation	Starting-point interpretation
Policy context	Mitigation policy, compensation policy	Adaptation policy
Main problem	Climate change	Social vulnerability
Main solutions to problem	Climate change mitigation, technical adaptation, compensation	Social adaptation, sustainable development
Policy question	What are the benefits of climate change mitigation?	How can the vulnerability of societies to climatic hazards be reduced?
Research question	What are the expected net impacts of climate change in different regions?	Why are some groups more affected by climatic hazards than others?
Purpose	Descriptive	Explanatory
Meaning of 'vulnerability'	Expected net damage for a given level of global climate change	Susceptibility to climate change and variability as determined by socioeconomic factors
Vulnerability and adaptive capacity	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Reference for adapt. capacity	Adaptation to future climate change	Adaptation to present climate variability
Starting point of analysis	Scenarios of future climate hazards	Present vulnerability to climatic stimuli
Main discipline	Natural sciences	Social sciences
Vulnerability approach	Integrated	Social constructivist
Qualification according to the terminology in Sect. 2	Long-term cross-scale integrated vulnerability [of a particular system] to global climate change	Current internal integrated vulnerability [of a particular group] to all relevant stressors
Reference	McCarthy et al. (2001)	Adger (1999)

Table 4: Two interpretations of vulnerability in climate change research (partly based on O'Brien et al., 2004a; Smit et al., 1999; Burton et al., 2002)

	Natural hazards	Climate change
Hazard characteristics:		
– Temporal	Discrete events	Long-term & continuous
– Dynamics	Stationary	Non-stationary
– Spatial scope	Regional	Global but heterogeneous
– Uncertainty	Low to medium	Medium to very high
– Attribution	Natural variability	Natural & anthropogenic
Systems of concern	Social systems & built infrastructure	All systems
System view	Static	Dynamic and adaptive
Consequences	Specific impacts	Broad range of impacts
Targets for risk reduction	Internal vulnerability	Hazard potential & internal vulnerability
Analytical purpose	Normative	Positivist & normative

Table 5: Characteristics of vulnerability assessments in the fields of natural hazards and climate change

cations for the conceptualization of 'long-term vulnerability to global climate change', which are discussed below.

1. Climate change is continuous.

   DRA is concerned with discrete hazard events, which are the cause of (additional) risk to a system. Climate change, in contrast, is a continuous process that may either increase or decrease baseline risk levels. Hence, assessments of the risks associated with anthropogenic climate change need to express risk levels in comparison to a baseline scenario.

2. Climate change is a long-term process attributable to human action.

   DRA sees climatic hazards as stationary and exogenous to the assessment, and assumes vulnerability to be constant. The long time scales of climate change, in contrast, require a dynamic assessment framework that accounts for uncertainty in future hazard levels and changes in all groups of vulnerability factors over time. Changes in internal vulnerability factors comprise those that are largely independent of climate change (such as socioeconomic and demographic development) as well as autonomous and planned adaptations caused by climate change. Estimates of the latter require consideration of the determinants of adaptation, *i.e.*, of 'adaptive capacity'.

3. Climate change is complex, global and spatially heterogeneous, and uncertain.

   DRA assumes that the *exposure* of a vulnerable system to a hazard can be characterized by the description of the hazard at the spatial scale of the hazard. In vulnerability assessments to global climate change, however, the large deviation between the scales of the (global) hazard and the (regional) exposure units does not permit the implicit equation of 'hazard' with 'exposure to the hazard'.

   Two identical systems at different locations are likely to experience different exposures (to regional climate change), such as reduced precipitation in one location and increased precipitation in the other, for the same magnitude of the hazard 'global climate change' (*e.g.*, expressed in terms of global temperature change). Furthermore, the same amount of regional climate change (*e.g.*, a given change in precipitation) may have very different impacts depending on the baseline climate (*e.g.*, whether the region is currently dry or humid). Hence, even if the two systems are identical (*i.e.*, their internal integrated vulnerability is the same), they may well experience very different impacts for the same level of global climate change Knowing the hazard (on a global scale) and the internal characteristics of a vulnerable system is thus *not* sufficient to characterize the risk of climate change to that system. We also need to consider the 'regional exposure factor', which describes how the global hazard will manifest at the location of the vulnerable system. The regional exposure factor, however, is subject to considerable uncertainty.

   The risk-hazard approach assumes that the 'risk' to a system is fully described by the two risk factors 'hazard' and 'vulnerability'. If we hold on to this idea, the question arises which of these two factors should include the regional exposure factor, *i.e.*, information about the regional heterogeneity of climate change and the associated uncertainty. I employ two examples to show that the most appropriate approach depends on the information needs of the particular vulnerability assessment. First, an assessment of the *vulnerability of a community's building stock to wind-storms* is likely to define the hazard at the local level (*e.g.*, by maximum wind speed) and to analyze plausible scenarios of changes in the frequency and magnitude of the hazard under climate change. While this approach is consistent with classical risk assessment, the results cannot be easily compared to other cities or scaled up to the national level without specific information about the particular climate scenarios applied in different local assessments, and about their respective likelihoods for various levels of global climate change. Second, a comparative assessment of the *vulnerability of several countries' staple food production to global climate change* needs to operationalize the hazard 'global climate change' in a way that is comparable across all countries considered. The principal idea is to specify the hazard at the global level (*e.g.*, as change in global mean temperature), and to use downscaled regional climate change scenarios to determine the corresponding changes in food production. In the presence of uncertainty about the regional exposure factor, the food production changes have to be determined for a range of plausible regional climate change scenarios.

In summary, the answer to the debated question whether aspects of exposure should be included in the definition of vulnerability depends primarily on the scale of the hazard in comparison to the vulnerable system. As the latter example shows, comparable estimates of the vulnerability of different communities *to global climate change* need to include the regional exposure factor in the definition of vulnerability.

4. Climate change may have multiple effects on a system.

   DRA typically uses a single metric (*e.g.*, economic loss, lives lost, percent damage) to describe the risk attributed to a specific hazard. Climate change, in contrast, typically has multiple incommensurable effects on societies and other vulnerable systems. For that reason, comprehensive characterizations of the vulnerability of a system to climate change generally require the use of multiple metrics (see, *e.g.*, Schneider et al., 2000; Smith et al., 2001; Jacoby, 2004).

Let us now come back to the original task of defining the 'future (or long-term) vulnerability to global climate change' in the context of the above discussion. The risks of future climate change to a system are determined by its *future exposure* to climatic hazards at the regional scale and by its *future sensitivity* to these hazards. Future exposure to regional climate hazards is determined by the *future hazard* level (*i.e.*, the future magnitude of global climate change) as well as by a *regional exposure factor* that describes the manifestation of climate change at the regional level. Future sensitivity to climate change depends on the *current sensitivity* of the vulnerable system as well as its *adaptive capacity* over time. In summary, future risk is determined by the future hazard level and three other factors: the regional exposure factor, current sensitivity, and adaptive capacity. The three latter factors are exactly those considered in the vulnerability definition from the IPCC Third Assessment Report (McCarthy et al., 2001): *"The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity."* Hence, the IPCC definition of vulnerability consistently describes the 'future (or long-term) vulnerability of any natural or social system to global climate change'. (Note that the IPCC glossary applies the terms 'vulnerability', 'adaptive capacity', and 'adaptation' to social as well as biophysical systems.) Luers et al. (2003) actually present a method for quantifying vulnerability (given the system, outcome variable, and stressor of concern) based on its exposure, sensitivity, and adaptive capacity. This characterization of the determinants of vulnerability to climate change is also in broad agreement with the framework presented in Downing et al. (2001), which distinguishes three domains of vulnerability: present criticality, adaptive capacity, and climate change hazard.

If applied to social systems, the IPCC vulnerability definition combines at least three of the four groups of vulnerability factors distinguished in Sect. 2.2 (with the possible exception of 'external socioeconomic factors'). On the account of the vulnerability factors applied, it corresponds to the conceptualization of vulnerability applied in integrated frameworks such as the hazard-of-place approach (*cf.* Table 2). However, the discussion in Sect. 3.1 did not consider dynamical aspects of vulnerability (*e.g.*, adaptive capacity), which are a key concern in the context of climate change.

In summary, the IPCC definition of vulnerability can be linked to the risk-hazard framework, whereby the classical definition of vulnerability focussing on the (current) 'sensitivity' of a system had to be extended to account for the heterogeneity and complexity of the hazard (by including a 'regional exposure factor') and for dynamical aspects (by including 'adaptive capacity'). This merging of aspects of 'exposure' into the conceptualization of 'vulnerability' may appear counterintuitive to scholars of traditional approaches to vulnerability assessment. However, it is necessary if the vulnerability to a spatially heterogeneous hazard that is larger than the system investigated, such as global climate change, shall be estimated comparably.

The IPCC definition of vulnerability does not contain any qualifiers. Some scholars have thus wrongly concluded that the IPCC intends to redefine vulnerability in *all* contexts whereas it only defined 'long-term vulnerability to global climate change'. This misunderstanding, however, reemphasizes the need for defining vulnerability in relation to specific hazards and outcomes, as called for by the conceptual framework of vulnerability proposed in this paper.

5 Summary and conclusions

'Vulnerability' describes a central concept in climate change research as well as in the research communities dealing with risk assessment, disaster management, public health, development, and secure livelihoods and famine. Each of these communities has developed their own conceptual models, which often address similar problems and processes using different language. Vulnerability, in particular, is conceptualized in many different ways. The existence of different conceptualizations and terminologies of vulnerability has become particularly problematic in research on global climate change, which brings together scholars from all of the communities mentioned above. Despite several attempts to resolve the conceptual confusion around 'vulnerability', none of the earlier frameworks has achieved this goal.

In this paper, I have presented a conceptual framework of vulnerability that combines three components: a terminology for describing any vulnerable *situation* (in terms of the vulnerable system, the valued attributes of that system, the hazards the system is exposed to, and a temporal reference), a classification scheme for vulnerability *factors* according to their scale and disciplinary domain, and a terminology for vulnerability *concepts* that is based on the vulnerability factors included. The resulting six-dimensional framework may appear somewhat complicated at first look. However, I have shown by way of example the importance of each dimension considered. I have also demonstrated that all simpler vulnerability frameworks are incomprehensive and inconsistent with each other. The relative simplicity of classical conceptualizations of vulnerability is only possible because they are based on certain assumptions about the issue of concern, such as that vulnerability is constant, that the hazard is discrete and stationary, that the exposure of a vulnerable system to a hazard is fully described by the hazard, or that social factors matter most. None of these simplifying assumptions can be taken as a given in the context of climate change.

The conceptual framework of vulnerability presented here is able to reconcile the large variety of vulnerability concepts found in the literature by clearly describing any vulnerability concept and by identifying the differences between various vulnerability concepts. It provides scholars engaged in interdisciplinary vulnerability assessments, in particular those concerned with climate change, with a tool for communicating clearly the vulnerability concept applied by their disciplines and to understand the concepts applied by colleagues with a different disciplinary background. In order for this framework to be most useful, it is indispensable that researchers applying it accept the legitimacy of different conceptualizations of vulnerability rather than engaging in fruitless debates about a single 'best' or 'correct' definition.

Applications of the vulnerability framework in this paper include a characterization of the major approaches to vulnerability research and a critical review of earlier attempts at developing conceptual frameworks of vulnerability (including Brooks, 2003). The discussion of the conceptualization of vulnerability in climate change research focusses on the applicability of the risk-hazard approach to the climate change problem and on the disputed vulnerability definition given in the IPCC Third Assessment Report.

Notes

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