

The vulnerability sourcebook and climate impact chains – a standardised framework for a climate vulnerability and risk assessment

Vulnerability
sourcebook
and climate
impact

35

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Abstract

Purpose – This paper aims to present the “Vulnerability Sourcebook” methodology, a standardised framework for the assessment of climate vulnerability and risk in the context of adaptation planning. The Vulnerability Sourcebook has been developed for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and has been applied in more than twenty countries worldwide.

Design/methodology/approach – It is based on a participative development of so-called climate impact chains, which are an analytical concept to better understand, systemise and prioritise the climate factors as well as environmental and socio-economic factors that drive climate related threats, vulnerabilities and risks in a specific system. Impact chains serve as the backbone for an operational climate vulnerability assessment with indicators based on quantitative approaches (data, models) combined with expert assessments. In this paper, the authors present the concept and applications of the original Vulnerability Sourcebook, published in 2015, which was based on the IPCC AR4 concept of climate vulnerability. In Section 6 of this paper, the authors report how this concept has been adapted to the current IPCC AR5 concept of climate risks.

Findings – The application of the Sourcebook is demonstrated in three case studies in Bolivia, Pakistan and Burundi. The results indicate that particularly the participative development of impact chains helped with generating a common picture on climate vulnerabilities and commitment for adaptation planning within a region. The mixed methods approach (considering quantitative and qualitative information) allows for a flexible application in different contexts. Challenges are mainly the availability of climate (change) and socio-economic data, as well as the transparency of value-based decisions in the process.

Originality/value – The Vulnerability Sourcebook offers a standardised framework for the assessment of climate vulnerability and risk in the context of adaptation planning.

Keywords Climate change, Adaptation, Vulnerability assessment, Indicators, Risk assessment, Impact chains

Paper type Research paper

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1. Background – Why a generic approach for a vulnerability assessment?

With the increasingly adverse effects of climate change, especially in developing and least developed countries (LDC) (Field *et al.*, 2014), adaptation to climate change stands high on the agenda of national and international programs. Already in 2010, the United Nations Framework Convention on Climate Change (UNFCCC) initiated the National Adaptation Plan processes (NAP) (UNFCCC, 2013), which aims at reducing the vulnerability of respective countries and most vulnerable groups by addressing medium- and long-term adaptation needs. In the context of NAPs, the LDC Expert group has emphasised the need for a vulnerability and risk assessment approach to support adaptation planning, particularly at the national, subnational and sector level (Least Developed Countries Expert Group, 2012). Furthermore, with larger funds for adaptation measures, for instance through the Green Climate Fund (GCF, 2011) the need for indicators to monitor and evaluate the success of adaptation measures in reducing risks and vulnerabilities is becoming increasingly prominent (Lamhauge *et al.*, 2012). Various generic guidelines and frameworks exist (CARE, 2009; UNDP, 2010; PROVIA, 2013). However, most of them lack instructions for an operational vulnerability and risk assessment that allows for comparison in time and/or space, which is a core pre-requisite for monitoring and evaluation purposes. Responding to this demand, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) commissioned the “Vulnerability Sourcebook” (Fritzsche *et al.*, 2015), a standardised methodological framework for climate change vulnerability assessments. This framework is applicable to vulnerability and risk assessments from national to local scale. It follows the full planning cycle of the adaptation process, from identification of the adaptation demand and selection of measures, to the monitoring and evaluation of the success of adaptation interventions in lowering vulnerability.

According to GIZ’s experience, (national) climate adaptation planning is often subject to a number of barriers (Table 1) such as limited availability of climate change information, lack of awareness of the need for climate resilient development, lack of capacity among key stakeholders and institutions, as well as lack of agreed priorities for climate resilient development (GIZ, 2014; Klein *et al.*, 2014; OECD, 2015). The authors argue that the structured and participatory approach of the sourcebook can help to overcome some of these barriers by capacity building of and co-development with key stakeholders and institutions from the beginning and by focussing not only on climate (change) as a driver but also on non-climatic drivers of climate vulnerability.

2. Conceptual framework: climate change impact, vulnerability, adaptation

The Sourcebook’s approach is based on the commonly applied concept of climate change vulnerability as proposed by the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Meanwhile, the current IPCC-AR5 WII report (Field *et al.*, 2014) introduced a new concept of “climate risk”, which is closer to the disaster risk community than the AR4 concept. It differs in terminology, but the general idea is the same: To understand the underlying root-causes of potential negative climate impacts, including climatic, natural, physical and socio-economic factors. The authors have already developed a set of instructions of how the Sourcebook can be applied with the IPCC AR5 climate risk approach (Zebisch *et al.*, 2017) and many of the most recent Sourcebook applications are already following this new AR5 climate risk approach. However, as the original Vulnerability Sourcebook and the lessons learnt from its first applications have not so far been published, the authors refer to the AR4 concept throughout this paper. A short summary of how the impact chain concept can be applied with the AR5 risk concept is given in Section 6.

According to the IPCC AR4, vulnerability is:

[. . .] the degree to which a system is susceptible to, and 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 change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (Parry *et al.*, 2007).

Various concepts exist that particularly differ on what the term “vulnerability” stands for, such as the disaster risk concept (United Nations Department of Humanitarian Affairs, 1992; Crichton, 1999), where vulnerability is only one aspect of the system, which determines the “harm” expressed as a “risk”. Often concepts are intermingled, which contributes to considerable confusion regarding the conceptualizations of vulnerability to climate change (Füssel, 2010).

For an in-depth discussion of terms and concepts of climate change and vulnerability in the AR4 logic see: Brooks, 2003; Dessai and Hulme, 2004; Adger, 2006; Füssel and Klein, 2006; Metzger and Schröter, 2006; Thomalla *et al.*, 2006; Füssel, 2007; O’Brien *et al.*, 2007; Hinkel, 2008, 2011; Wolf *et al.*, 2013. For a discussion on the IPCC AR5 concept of climate risk see Section 6 as well as Oppenheimer *et al.*, 2014; Zebisch *et al.*, 2017; Adger *et al.*, 2018.

In accordance with the IPCC-AR4 definition, the Sourcebook distinguishes between three key components that determine vulnerability to climate change: exposure, sensitivity, and adaptive capacity. Furthermore, in-line with Schröter *et al.* (2005); Metzger and Schröter (2006) and others, the component of “potential Impact” as an intermediate component was added.

Exposure (E) defines the character, magnitude, and rate of change and variation in the climate to which a system is exposed. Typically, exposure includes factors such as temperature, precipitation, climatic water balance, as well as extreme events such as heavy rainfall or meteorological droughts.

Sensitivity (S) determines the degree to which a system is adversely (or beneficially) affected by a given climate (change) exposure. In the author’s concept, sensitivity may be determined by (a) natural/physical factors of a system such as ecosystem types, land cover, slope, water holding capacity and erodibility of soils, (b) natural/physical factors related to human land management activities and infrastructure, such as the existence and quality of dikes, terraces, irrigation systems, houses, roads, electrical grids, (c) societal factors, such as population density or age structure.

Potential impacts (PI) are the combined effect of exposure and sensitivity without additional adaptation activities. For instance, torrential rain events (exposure) in combination with steep slopes and sandy soils (sensitivity) will result in erosion, loss of land and, consequently, loss of yield (potential impact). Climate change impacts can be more direct, such as erosion, or indirect, such as loss of income due to a reduction in agricultural yields.

Adaptive capacity (AC) describes the ability of a society, a social group or individuals to actively adapt to climate change, climate variability and climate extremes by moderating potential damages, taking advantages of opportunities, or coping with the consequences. Compared to the IPCC AR4 definition (Parry *et al.*, 2007), the (autonomous) adaption of ecosystems is explicitly excluded, which, in the author’s understanding, is part of sensitivity. Factors which determine adaptive capacity include economy, governance, knowledge, and available adaptation options (ecosystem-based as well as technical), (Adger *et al.*, 2004; Preston *et al.*, 2009).

Adaptation measures and their effect have not yet been conceptually integrated into the vulnerability concept. Adaptation is the process of adjustment to actual or expected climate

Table 1.
Typical barriers in
(national) adaptation
planing and potential
contribution of the
vulnerability
sourcebook to
overcome them. Own
summary

	Climate change information	Climate resilient development awareness	Priorities for climate resilient development	Capacity of stakeholders and institutions	Learning, monitoring and reporting on progress
Barrier	Descriptive, too broad/narrow, methodologically flawed data; lack of evidence about interplay between adaptation measures and development goals	Limited awareness; decision makers underestimate relative importance of adaptation measures in relation to other development goals	Adaptation priorities based on limited information and stakeholder involvement; poor reliability, ownership and legitimacy	Limited ability of stakeholders and institutions to manage climate information; limited science-policy integration	Lack of capabilities and knowledge to determine, measure and report on the achievement of adaptation objectives, thereby improving adaptation planning
Contribution Sourcebook Vulnerability	Demand-driven, scaled, empirically grounded data	User-friendly evidence on climate impacts, vulnerabilities, as well as the relative importance of adaptation measures	Participatory and informed approach to improve reliability, ownership and legitimacy of adaptation priorities	Involvement and capacity building, development of national climate service providers	Providing information for determining demand-driven adaptation objectives , creating a baseline, and by repeating the assessment, providing information on progress that can feed into a reporting system

and its effects (Field *et al.*, 2014). Adaptation can cover a wide range of approaches, such as ecosystem-based approaches (natural retention areas for flood protection), technical measure (e.g. dikes), information-based measures (training on climate change adaptation), economic measures (diversification of production), or governance and participation measures (e.g. round tables). For ecosystem based approaches see the latest publication on climate risk assessment in the context of Ecosystem based Adaptation (Hagenlocher *et al.*, 2018)

The authors propose to integrate adaptation into the vulnerability concept by assuming that adaptation lowers vulnerability by lowering sensitivity and/or increasing adaptive capacity (see Figure 1).

2.1 Can vulnerability be measured? Or: how to assess vulnerability?

The authors fully support Hinkel’s statement that:

vulnerability cannot be measured because vulnerability does not denote an observable phenomenon. Since vulnerability is a theoretical concept, it is more accurate to speak about making the concept operational instead of measuring it (Hinkel, 2011).

As a result, the authors prefer to use the term *assessing* instead of *measuring* vulnerability and propose a system of how to operationalise this assessment. The authors thus take into account that the concept of vulnerability of a given system is based very much on normative values and questions such as: what do we want to protect? How important or relevant is a potential impact for the system’s function? Due to the value-based character of vulnerability, a vulnerability assessment can never be objective and independent of the values of the “owner” of this system, which may even differ between different groups of stakeholders.

A common and valid approach to take into account the qualitative and value-based nature of vulnerability, particularly at the local scale, is to base the assessment on a bottom-up and participatory appraisal, using mainly qualitative information and narratives (CARE, 2009). However, this is barely possible for larger scales (trans-national to global). For these, a set of top-down approaches for data driven vulnerability assessments exists, which are based on standardised composite indicators, mainly for climate change, partly complemented by socio-economic indicators (Baettig *et al.*, 2007; Piontek *et al.*, 2014; Maplecroft, 2015). Here, value-based decisions are usually implicitly

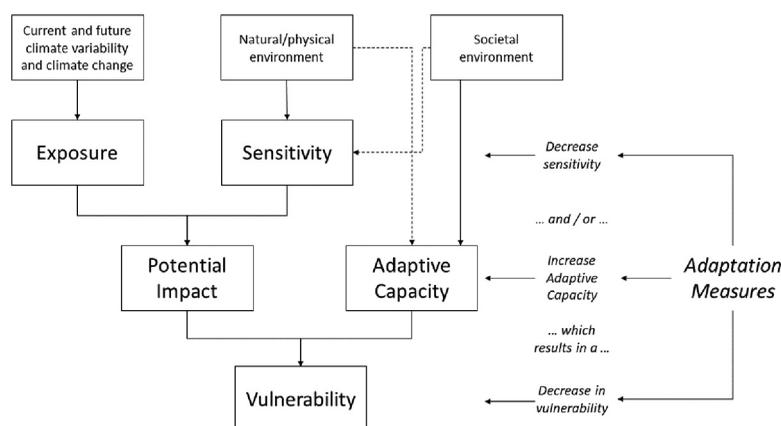


Figure 1.
Concept of climate
vulnerability applied
in the Sourcebook

made through the selection of indicators. For a discussion on global indicators for hot-spot mapping see [de Sherbinin \(2014\)](#).

Despite this restriction for measuring vulnerability, the demand of decision-makers and funding agencies for *comparing* the vulnerability across spatial regions, even at the sub-national scale (e.g. municipalities), or *monitoring and evaluating* vulnerability through time (e.g. before and after an adaptation measure) requires an assessment scheme, which is not only based on narratives but reproducible and transparent. This calls for the use of numbers at least on an ordinal scale.

3. A standardised vulnerability assessment in eight steps

The concept proposed here is an operational framework to *assess* vulnerability built on a set of impact chains and indicators that are co-developed with stakeholders. This concept is based on a methodological framework that was first applied for climate change related vulnerability assessments in the Alpine region ([Schneiderbauer et al., 2013](#)). The approach allows for the integration of different data sources such as measurements, models, surveys, and expert-based as well as participatory appraisals, and makes value-based aspects explicit and participative. The framework, with all its elements and steps, is strictly oriented towards its suitability for adaptation planning.

The outcomes are assessments of relevant sub-systems at a level of detail that fits to the adaptation planning in a given setting, and not one single standardised composite indicator for vulnerability.

The temporal reference of the assessment preferably includes current vulnerability to present climate extremes or trends as well as vulnerabilities for different future time slices (e.g. 30-year climatological mean “valid” for 2030 or 2050). The inclusion of current climate vulnerability allows for the exploitation of stakeholder observations and experiences concerning the root causes of observed climate impacts. The knowledge of current and future climate vulnerability is an important entry point for planning effective adaptation measures. The Sourcebook presents the assessment approach in eight steps ([Table 2](#)).

3.1 Step 1 – preparing the vulnerability assessment (VA)

The objective of this first step is to clarify the context of the VA and to define its particular scope. The context includes the objective (e.g. development of a national adaptation strategy), the existence of studies and knowledge (including data and methods), and the target group of the VA, as well as the availability of resources (persons, time, and money). This first working step of “scoping” results in decisions on topics (sectors, social groups to be considered), the spatial scale (e.g. national, provinces), the temporal scale (e.g. present or future climate scenarios) and the methodological approach to be applied. Finally, a VA implementation plan should define all concrete activities and tasks. The authors recommend already involving stakeholders in this phase and organising the scoping through a kick-off workshop.

3.2 Step 2 – developing impact chains

Impact chains are conceptual models describing climate impact as cause-effect relationships within a socio-ecological system. Impact chains are the author’s major approach for the question of how to operationalise vulnerability. Applying the IPCC AR4 concept strictly (Section 2) the Sourcebook’s impact chains describe the relations between the components of vulnerability, which are the climate signals (exposure - E), the system’s sensitivity (S) towards these signals and its adaptive capacity (AC). Intermediate outputs are potential impacts (PI), as a function of E and S. The final output is Vulnerability (V), a function/

Table 2.
Eight steps of the
vulnerability
assessment

Step	Objective
1 Preparing the Vulnerability Assessment	Definition of objective and scope. Estimate of resources needed
2 Developing Impact Chains	Definition of the potential impacts addressed in the vulnerability assessment; development of impact chains
3 Identifying and Selecting Indicators	Selection of indicators for the assessment, based on the relevant factors from Step 2
4 Data Acquisition and Management	Guidance on data collection, database construction and linking relevant data to the chosen indicators
5 Normalization and Threshold Definition	Transfer of the different data sets into unit-less values on a common scale
6 Weighting and Aggregation of Indicators to Vulnerability Components	Demonstrate how to assign weights to the various indicators and how to aggregate indicators to vulnerability components
7 Weighting and Aggregating of Vulnerability Components	Aggregate the vulnerability components exposure and sensitivity to potential impact and potential impact and adaptive capacity (AC) into composite vulnerability indicator (s)
8 Presenting the Outcomes of the Vulnerability Assessment	Summary and presentation of the findings of the vulnerability assessment

relationship of PI and AC. For each vulnerability, component more than one factor can be defined. Furthermore, for each system more than one vulnerability can be defined. In the author's approach, each vulnerability refers to a particular potential impact. The vulnerability of the total system, particularly in multi-sectorial studies, should be subdivided into multiple meaningful vulnerabilities. Figure 2 illustrates a simplified impact chain for one particular vulnerability ("vulnerability of village farmers to erosion and land degradation") from the Pakistan case study.

While impact chains should build on existing scientific knowledge, it is also recommend developing impact chains in a participatory manner together with experts and key stakeholders in order to match them with the concrete adaptation context. In the cases studies, the authors started from a broad collection of potential climate impacts on a given system, which were narrowed down in a participatory prioritisation process by using standard pinboard moderation techniques (Figure 3).

Consequently, for all relevant impacts, impact chains were set-up. To be applicable in an operational assessment scheme, impact chains need to be further reduced, simplified and fine-tuned in an iterative process taking into account relevance, scientific knowledge as well as potential indicators for a single factor. If data availability seems to be poor for a prioritised factor, it is recommended nevertheless keeping this factor in the chain and searching either for a proxy indicator or the consideration of an expert-based evaluation in the subsequent steps. The underlying hypothesis of this more holistic approach is that purely data driven approaches can only cover a certain portion of vulnerability, often restricted to some direct impacts whilst skipping important aspects of sensitivity and adaptive capacity.

Adaption measures could already be conceptually integrated into the chains during this phase. In the example of Figure 2, reforestation or an increase of rainwater harvesting could decrease vulnerability. Impact chains are not just the backbone of the VA, but already a result per-se, as they conceptualise the causes of climate vulnerability within a systematic and agreed approach.

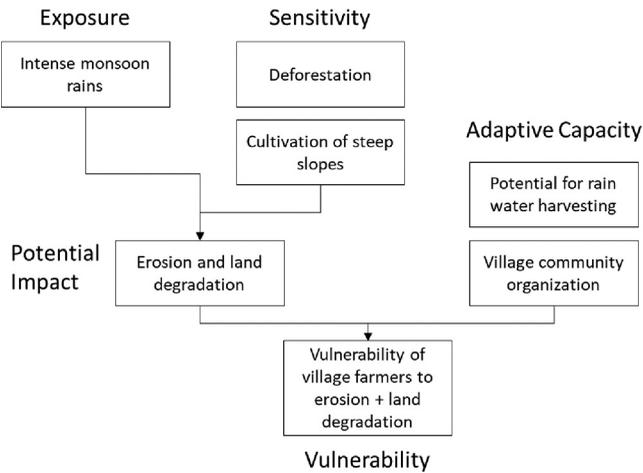


Figure 2.
Simplified impact chain for the vulnerability of village farmers to erosion and landslides

Source: From a case study in Pakistan at the municipality level

3.3 Step 3 – identifying and selecting indicators

While impact chains are the “back-bone” of the assessment approach, indicators are the “flesh on the bones”. Usually, only a few potential impacts can be assessed through existing models (e.g. in hydrology) in most cases appropriate indicators have to be identified for all relevant factors of the impact chains and connected to the three components of vulnerability (exposure, sensitivity, adaptive capacity). The choice of appropriate indicators depends very much on the scope of the study and on data availability. However, good indicators share common attributes in being relevant, measurable, practical and clearly interpretable in the direction of climate vulnerability (e.g. high values contribute to a high vulnerability). “Measurable” means that it must be possible to assign categorical or ordinal value to an indicator. For example, “poverty level in the population” is not a sufficiently explicit indicator for measuring the factor “poverty”. A good indicator instead would be “percentage of households on income of less than US\$1 per day”. For an overview of indicators used in the three case studies (Tables 4–6).

3.4 Step 4 – Data sources and data acquisition

Tables 4–6 illustrate that data sources and methods of data acquisition for indicators depend very much on data availability and the set-up of the vulnerability assessment (scale, resources and temporal reference). For exposure indicators (meteorological parameters), data can stem from national weather services (for the past) and climate model runs (for the past and future). Today, the model results from General Circulation Models (GCM), which have been used within the IPCC AR5 reports (IPCC, 2013), are available through the CMIP5 - Coupled Model Inter-comparison Project (Taylor *et al.*, 2012). For many regions in the world, downscaled climate model runs are available through Regional Climate Models (RCMs), for instance through the Coordinated Regional Climate Downscaling Experiment (CORDEX) (Giorgi *et al.*, 2009). CORDEX scenarios are based on climate model ensembles representing different combinations of GCMs and RCMs. In particular, this ensemble approach allows for a consideration of all aspects of model uncertainty in climate scenarios (Tebaldi and Knutti, 2007). Despite all these existing data, the author’s experience in the case studies has shown that a common limitation for sub-national

(normalisation) but at the same time an important value-based decision. Objective information (e.g. number of days with heavy rain events) is transformed into an explicit interpretation of the importance of a specific parameter value on the vulnerability of the system. The authors propose using a range from 0 to 1 (equals 0% to 100%), with “0” meaning: “uncritical, optimal state” and “1” meaning “critical, function of system threatened”. The decision on thresholds for “0” and “1” should be taken context specific (for the specific case and the specific vulnerability). The way in which indicator data is transformed into this range depends on the scale level (e.g. metric, ordinal, nominal level). Metric data could be normalised through a modified min-max transformation, setting a maximum for a parameter value that would lead to a critical state and a minimum to a value that is related to an uncritical state. Ordinal or nominal values need to be transformed by transfer schemes, which need to be thoroughly co-developed with stakeholder and experts for the particular system under consideration. For an easier communication, school grade-type schemes (such as values from 1–5) could be used and transformed into the 0 – 1 scheme afterwards. See Figure 4 for an example of a transfer scheme used in the Burundi case study. The scheme transfers ordinal values (classes of population density) through school grades into the unit-less scheme from 0 to 1. Thresholds for population classes stemmed from a discussion with local experts on the carrying capacity and the sustainability of land-use related to population density. The resulting transfer scheme is specific to the country of Burundi and would look very different for regions in other climate zones.

3.6 Step 6 – weighting and aggregation of indicators to vulnerability components

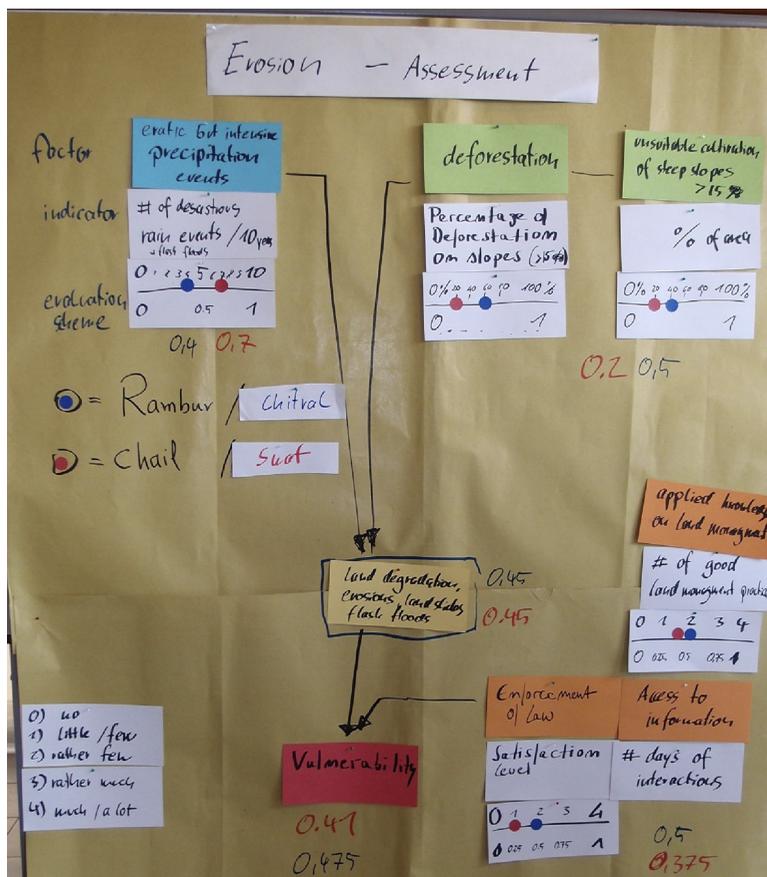
In the next step, indicators are aggregated within each single vulnerability component (exposure, sensitivity and adaptive capacity) (Figure 5) to composite indicators. Due to normalisation in the step before, indicators can be mathematically aggregated in a weighted aggregation scheme. Weights can be applied if experts and stakeholders consider factors within one vulnerability component as not of equal importance. Actually, in two of the three case studies presented here (Burundi, Pakistan), it was decided together with the stakeholder not to apply any weighting. Instead, the normalisation and threshold definition of each factor (see step 5) was done in a way that “1” = critical stands for a similar contribution to the overall risk. In Bolivia, a study on a very local scale, stakeholders decided for weighting for certain adaptive capacity factors. There is a huge range of potential aggregation methods from simple weighted arithmetic mean to all variants of Pythagorean means, such as a weighted geometric mean or weighted harmonic mean. Whilst an arithmetic mean tends to level out extreme values, it has the advantage of simplicity, which makes it easy to understand and interpret. Geometric and harmonic means, in contrast, have the advantage of a lower compensability of low values. In the cases presented here, the authors applied arithmetic mean for the bottom-up participatory case studies (e.g. in Pakistan), where the number of factors were low, and comprehensibility was important. For studies that are



Colour code	# inhabitants / km ²	Effect on sustainability of land use	School grade	Final value 0..1
	<= 100	optimal	1	0
	101 - 200	rather positive	2	0.25
	201 - 300	neutral	3	0.5
	301 - 450	rather negative	4	0.75
	> 450	critical (function of system under thread)	5	1

Figure 4.
Example of a transfer scheme from the Burundi case study

Note: Evaluation of population density and its effect on the sustainability of land use as one factor for sensitivity



Notes: The impact chain was generated during a workshop in Pakistan. Indicators were identified and a preliminary expert assessment carried out
Source: © Marc Zebisch

Figure 5. Simplified impact chain for vulnerability towards land degradation, erosion, landslides and flash floods, due to heavy rain events

more data driven and cover many factors, a geometric or even harmonic mean might be more recommendable. The final output of step 6 is an evaluation for each of the components of vulnerability.

3.7 Step 7 – weighting and aggregating of vulnerability components

In a last aggregation step, the single components are aggregated to a composite vulnerability indicator for each vulnerability, applying the same aggregation method that has been chosen for step 6 (Figure 5). If impact chains have been built for more than one vulnerability, single vulnerabilities could also be further aggregated using the same method, for instance to one vulnerability per sector. The authors do not recommend aggregating the results to an overall vulnerability score, as the interpretability will become difficult and the information content for adaptation planning will be low.

3.8 Step 8 – presenting outcomes

There are numerous ways of presenting the outcomes of a vulnerability assessment. The most important means of presenting the results of the vulnerability assessment to an external audience is a vulnerability assessment report. The report will contain the results of the vulnerability assessment but also an explanation of the whole process, starting from the objectives and the scope. If the assessment was a spatially explicit assessment, results can be presented as vulnerability maps (see example from Burundi in Section 4). In other cases, they can be presented as tabular data, illustrated by spider web diagrams or similar means. It is important to complement the results of the semi-quantitative assessment with narratives, which include all the results from discussions, interviews, etc. which could not be squeezed into numbers and indicators. Finally, a relation to the adaptation context should be made explicit. This could be done by highlighting regional hot-spots or critical elements and social groups belonging to the system for adaptation planning.

4. Results from case studies

Here three case studies are presented, each with very different settings. Table 3 summarises the scope of the three case studies. Tables 4–6 list for each case study the most relevant factors, indicators and data sources used in the vulnerability assessment.

	Bolivia	Pakistan	Burundi
Context + Purpose	Assess vulnerability of small farm holders and evaluate effects of recent adaptation measures	Identify adaptation measures and evaluate their influence on the vulnerability of local communities	Identify national and local hotspots for planning adaptation measures
Spatial scale	Village to individual farm	Two districts of Swat and Chitral+ village level	Nationwide, followed by a more in-depth assessment at local scale in identified subnational hotspots
Temporal scale	Periods before and after introduction of measures, near future	Vulnerability to current climate variability and climate extremes	Three time periods: present, 2031–2060, and 2071–2100
Relevant topic	Climate change and water supply in agriculture	Climate change impacts on agriculture and (agro-) biodiversity	Climate change impacts on agriculture (production and soil erosion) and health (malaria prevalence)
Proposed input + methods	Combination of model-based, data driven approaches and expert opinion method	Expert-opinion method conducted during a stakeholder workshop, participatory rural appraisal (PRA)	Combination of model-based and participatory approaches. Resulting maps at the national level. Quantitative analysis at the national level, more qualitative analysis at the local level
Number of external stakeholders/ experts involved	6 (including local water engineers, experts on rural development)	~20 (including local agricultural extension officers, met-office, . . .)	~30 (representative from national ministries + departments, universities, ..)
Time needed	10 months	6 months	11 months

Table 3.
Scope of the three case studies

Table 4.
Factors, indicators
and data sources for
the Bolivia case
study

Case study Component	Factor	Bolivia – water scarcity for irrigation in agriculture	
		Indicator(s)	Data source
Exposure	Precipitation	monthly precipitation [mm]	Measurement (past)
Sensitivity	Temperature	Tmin and Tmax [°C]/month	Climate Scenarios (future)
	Crop Type	Type of crop, month of sowing, area cultivated	Field data (past) Scenarios (future)
Potential Impact (if modelled)	Efficiency of irrigation system	% area covered, water losses [mm]	Field data (past) Scenarios (future)
	Water availability for crops	Water availability for crops [mm],	agro-hydrological model ABRO3.1
Adaptive Capacity	Resources	Land availability	Expert judgments (workshop output)
		Technical Assistance	
		Access to information	
	Governance	Proximity to trade channels Efficiency of farmer’s irrigation organization	
	Knowledge	Knowledge about new crops Crop management knowledge Adjustments to agricultural calendar	
Technologies	Soil management Seed management Plague and disease control		

Table 5.
Factors, indicators
and data sources for
the Pakistan case
study

Case study Component	Factor	Pakistan – erosion and land degradation	
		Indicator(s)	Data sources
Exposure	Intense monsoon rains	# of intense rain events/ 10 years	Measurements
Sensitivity	Deforestation on steep slopes	% of deforestation on slopes >15°	Participatory Rural Appraisal (PRA)
	Cultivation on steep slopes	% or area of cultivation of slopes >15°	
Adaptive Capacity	Rainwater harvesting	% of potential water harvesting exploited by mud ponds or cemented ponds	
	Village community organization	% of villages which are part of village communities	

In all three case studies, at least two stakeholder workshops have been conducted. Stakeholder and experts were typically representatives from national ministries and departments, such as the Hydro-Met services, as well as representative at the local level (e.g. agricultural extension officers). In a first workshop, key impacts were identified, and impact chains developed in a participatory manner. Afterwards, data collection and surveys were conducted to populate indicators in a quantitative (e.g. climate data, erosion modelling) or qualitative manner (e.g. expert surveys on adaptive capacity). In a second workshop, results from the data collection were presented and assessed by experts, based on agreed assessment schemes, which were developed together with the external experts and stakeholders. This intermediate assessment was then aggregated and reviewed, first by the consultant team and then by the local experts in order to get to the final result.

Case study Component	Burundi – agricultural production		
	Factor	Indicator(s)	Data sources
Exposure	Change of precipitation	Amount of rainfall in mm Amount of groundwater recharge rate in mm	Regional climate model Hydrological model
	Change of temperature/ change of precipitation	Climatic water balance in mm: amount of rainfall in mm – amount of potential evapotranspiration in mm	Regional climate model, hydrological model
Sensitivity	Population density	Number of inhabitants per km ²	Census data 2008 (Institute of Statistics of Burundi)
	Use of agricultural inputs	% of households using chemical fertilizer	National agricultural survey 2013 (Burundi Ministry of Agriculture)
	Slope type	Slope gradient in % and slope length in m	Digital Elevation Model (Burundi Institute of Geoinformatics)
	Vegetation cover	Type of vegetation cover	AfriCover (FAO)
Potential Impact (if modelled)	Field sizes and access to arable land	Average field size per household in ha	National agricultural survey 2013 (Burundi Ministry of Agriculture)
Adaptive Capacity	Financial resources	Average income per household in FBU/year % of non-agricultural income per household in FBU/year	National agricultural survey 2013 (Burundi Ministry of Agriculture) National agricultural survey 2013 (Burundi Ministry of Agriculture)
	Access to agricultural inputs	Time to access the nearest marketplace per household in min	National survey on indicators of well-being 2006 (Ministry of Planning, Development and National Reconstruction)
		Time to access the nearest functional route in every season in min	National survey on indicators of well-being 2006 (Ministry of Planning, Development and National Reconstruction)
	Local knowledge to mitigate negative impacts	Frequency of attendance of primary and secondary schools per households in % % of literate women	National survey on indicators of well-being 2006 (Ministry of Planning, Development and National Reconstruction) National survey on indicators of malaria 2012 (Burundi Institute of Statistics)

Table 6.
Factors, indicators and data sources for the Burundi case study – vulnerability to erosion

4.1 Bolivia

The community of Chullcu Mayu, Bolivia, is located on an altitude of 3500 m in the Cordillera Oriental, 75 km from the city of Cochabamba. The area of interest is a community of 97 peasant families, with an agricultural area of 61 ha. The problem for agricultural production in this region is water scarcity due to erratic rainfall and low efficiency in their traditional irrigation systems. With climate change, precipitation is projected to decrease further in this region. Within the Sustainable Agricultural Development Program (PROAGRO), Farmers in the Chullcu Mayu community have implemented a new irrigation system along with a training program and a farmer's organisation as a measure to adapt to current climate variability and future climate change. Hence, the objective of the

vulnerability assessment was to quantify to what extent climate vulnerability has been reduced from a period without irrigation system (1960 – 1990) to the period after the introduction of the irrigation system (1991 – 2011). For the Chullcu Mayu case study, it was possible to follow a mainly data driven approach. The impact of climate change and the irrigation system on water availability for agriculture was estimated quantitatively with and without the irrigation system. The estimation was based on climate data and hydrological data, and conducted with the help of the agro-hydrological model ABRO3.1 (Componente de Asistencia Técnica del Programa Nacional de Riego, 2002). Adaptive capacity was assessed by expert judgement for four single factors (Resources, Governance, Knowledge, Technologies). Within each factors a set of sub-factors was defined and assessed separately. For instance, the adaptive capacity in the field of “Knowledge” was subdivided into knowledge on introduction of new crops, knowledge on crop management, adjustment to agricultural calendar. See Figure 6 for the impact chains and Table 4 for the indicators. Further information on the Bolivia case study can be found in the annex of the Sourcebook (Fritzsche *et al.*, 2015)

The results indicated, that the introduced adaptation measures have significantly lowered the vulnerability from 0.71 (rather negative, high vulnerability) before the introduction of the irrigation system (1960–90) to 0.21 (rather positive, low vulnerability) after the introduction (1991–2011), mainly by reducing the potential impact through increasing the proportion of cropping area with sufficient water supply, but also by increasing the adaptive capacity of the system. For adaptive capacity the most relevant factors were improvements in governance (introduction of a farmers organisation) and knowledge (through training programs).

4.1.1 *Pakistan.* The two districts of Swat and Chitral are located in the Pakistani Hindukush mountains and cover an area of roughly 20,000 km² with around 2.5 million inhabitants. In the last decades, climate extremes in combination with deforestation and inappropriate land management (cultivation of steep slopes without erosion protection, unsuitable crops) posed threats to food security and ecosystems. Here, an explorative vulnerability assessment with a focus on climate change impacts on agriculture, forestry and biodiversity, was conducted by a local consultant (trained by the authors) for 10 villages within the region (Hussain, 2014). The assessment intended to support the identification and implementation of community-driven and ecosystem-based adaptation measures to climate

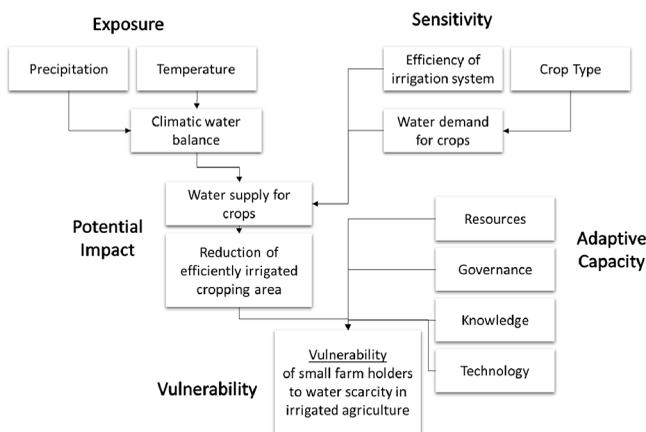


Figure 6. Impact Chain for the Bolivia case study: Vulnerability of small farm holders to water scarcity in irrigated agriculture

change in the framework of the GIZ project “Conservation and Sustainable Management of Biodiversity in Khyber Pakhtunkhwa (BKP)”. The Pakistan case study was focussing on the current vulnerability of village farmers and their agricultural land to erosion and landslides. The identified factors (Table 5) which lead to erosion and land degradation were; intense monsoon rains, for exposure; deforestation and cultivation on steep slopes, for sensitivity; and the extent of rain-water harvesting measures to prevent land degradation in dry periods as well as the quality of village community organisation, for adaptive capacity. Factors were identified and assessed separately for the two districts in a participatory way using scores (from 0 to 1001) in one stakeholder workshop with national and local experts and complemented by a Participatory Rural Appraisal (PRA) undertaken by a local consultant within selected communities.

The results of the assessment indicate that the most important components for understanding the vulnerability of and the difference between the two regions is sensitivity and adaptive capacity and not the climate signal itself. According to the experts, the single most important factor contributing to the vulnerability of the region is deforestation (rated by the experts in one region as 0.75 = “rather critical” on a scale from 0= “optimal” to 1= “critical”, based on an estimate of deforestation in the region). But also, the lack of appropriate practices such as rainwater harvesting, were found as critical. Based on the findings of the vulnerability assessment, several recommendations to reduce climate vulnerability were developed, such as reforestation with broad leaved indigenous trees, a better protection of gullies, and construction of small water reservoirs and check dams, or capacity building measures such as awareness raising on appropriate land and water management.

4.1.2 Burundi. Burundi lies in the centre of Africa and is one of the smallest countries on this continent. It has one of the highest population densities worldwide, with approximately 11 million people living in an area of approximately 28,000km². A large part of Burundi’s population lives in poverty and about 90% of Burundians are dependent on subsistence farming. The vulnerability assessment in Burundi focussed on the soil and water resources as crucial factors for both the agriculture sector and erosion processes. A more detailed description of methods and results are report in [Schneiderbauer et al., 2020](#). For vulnerability to erosion, 14 indicators for the three components of vulnerability were identified (Table 6) and processed to GIS information layers. The indicators selection has been a two-step procedure. First, potential indicators were identified by local scientists and practitioners during a 2-days-workshop. Following, a final selection was made by a core group of local experts taking into consideration the criteria relevance, analytical soundness, timeliness, accessibility, and clarity. Results were first aggregated for each component. Finally, all three components were aggregated into one vulnerability map (Figure 7). The results informed the GIZ – led technical cooperation project ACCESS (Adaptation au changement climatique pour la protection des ressources en eau et sol) that deals with climate change impacts on soil and water resources, as well as adaptation priorities at various scales (from local to national).

The entire assessment procedure was carried out with strong stakeholder and local expert participation who were able to contribute at two different levels of intensity. A wider group of actors participated at four workshops organised during the 11 months period of the main project work. A smaller group of selected core experts accompanied and advised the project more intensively and more frequently throughout the project work by means of meetings, which were arranged according to project needs.

The vulnerability assessment was based on both quantitative and qualitative approaches. Quantitative methods comprised climate and hydrological modelling as well as spatial analyses of various statistics. Qualitative methods complemented the quantitative

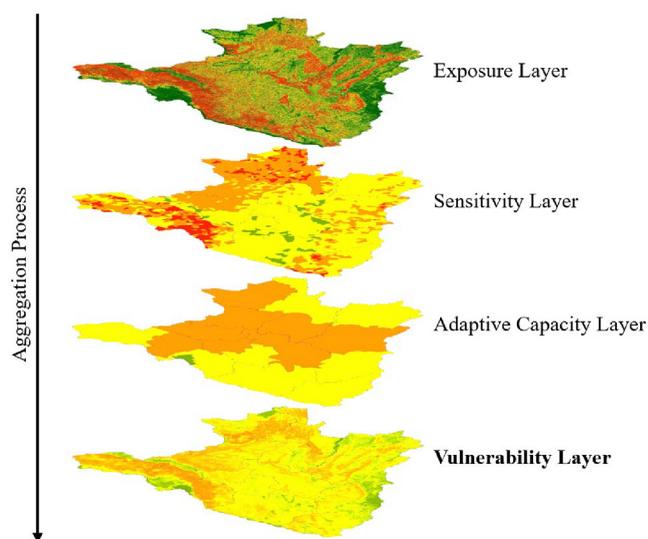


Figure 7.
Aggregation of
Vulnerability
components for the
Burundi case study –
Vulnerability to
erosion

results and allowed for the generation of context specific assessment rules. The assessment of the vulnerability to erosion was based on (1) the results of the model RUSLE (Revised Universal Soil Loss Equation) in which the bio-physical parameters of precipitation, temperature, vegetation and relief were incorporated and (2) the social-economic parameters linked to population, wealth and knowledge.

The core working steps of the vulnerability assessment at national scale comprised:

- climate and hydrological modelling;
- the development of climate impact chains;
- the selection, classification and aggregation of vulnerability indicators; and
- the generation of vulnerability maps.

The Burundi study showed that the country's erosion vulnerability hotspots are located in the northern and particularly the north-western part of Burundi, whilst vulnerability to drought is highest in the northeast and southeast of the country. The assessment in Burundi revealed that in addition to the selection of suitable indicators, a key challenge of the applied methodology is to evaluate the relevance of certain indicator values for vulnerability. That is, the allocation of the indicator values to certain classes associated with lower or higher vulnerability values is a crucial task, which is especially difficult for sensitivity and adaptive capacity indicators, as those factors are often less tangible. For example, in the case of the indicator "per cent of literate women" it is difficult to define the threshold of a percentage value that distinguishes between classes defining different degrees of adaptive capacities. In the case of Burundi, this problem was addressed by integrating local knowledge and expertise in order to obtain a meaningful classification of the various input indicators.

5. Lessons learnt from case studies

In addition to the experiences collected from the three case studies presented in this paper, the authors systematically collected feedback on the sourcebook approach in

2018 as part of an internal GIZ project using structured interviews with nine GIZ experts as well as external consultants which have applied the sourcebook. Results have shown that the sourcebook methodology is appreciated by development cooperation organisations as well as by stakeholders that is local experts and decision makers, as well as civil society organisations but also revealed limitations and bottlenecks.

Stakeholders perceived particularly the concept of impact chains as very helpful. According to their feedback, impact chains helped to obtain a clear picture of the links between climate change, key vulnerabilities and the complex web of underlying causes and effects. They appreciated the participatory approach, which often revealed the very specific vulnerabilities of their system and led to an agreed understanding of their climate vulnerability. Based on the impact chains, targeted discussions on potential entry points for adaptation measures were already fostered.

The fact that the actual vulnerability assessment is based on a set of specific indicators that are selected in accordance with the specific impact chains and not on any generic indicator scheme, supported the acceptance of the assessment approach. Furthermore, the mixed-method approach, which allows for the integration of quantitative, data driven approaches (e.g. for climate data) with more expert based assessments in a common assessment scheme, was very well accepted.

The discussion about the data required for the climate, land-use, ecosystem, as well as socio-economic aspects contributed to an increased knowledge of local stakeholders concerning existing and publicly accessible data sets (such as climate scenarios or data on land cover).

However, the authors also faced challenges during the course of the assessment. An initial challenge was the strong requirement for resources and experience for a data driven analysis, particularly if it was spatially explicit (such as the Burundi case). This included accessing, handling and analysing climate data and climate scenarios, impact models (such as hydrological models), as well as the quality control of socio-economic data. In practice, accessing and sharing data across different ministries, agencies and other parties created a bottleneck as data sharing policies and agreements were required and these took time to set up.

A second challenge is related to a discussion about the objectivity or replicability of qualitative assessment approaches. In all the case studies presented it became evident that a purely data driven approach could not cover the most relevant potential impacts. As a result, the inclusion of more qualitative approaches based on expert judgement and narratives was a very important element. However, it is challenging to make the process of such an evaluation as representative as possible by including enough people, having a good mix of stakeholder and experts, and asking the right questions, as well as correctly evaluating the answers. Expert-based assessments also have their drawbacks if the assessment needs to be repeated after a certain period of time to monitor the success of an adaptation activity. On the other hand, it can be argued that data-driven approaches also lack objectivity and that only their integration with expert based methods allows for the representation of many of the most important aspects of vulnerability in a given context.

A third challenge concerns the value-based character of any risk and vulnerability assessment. The process of the assessment is made up of many decisions that are not (solely) based on scientific knowledge, expertise or experience. These decisions need to take into consideration the political, societal, cultural and economic priorities within the local context. The local stakeholders and experts involved in the studies

often hesitated in taking such decisions. The value-based character of an assessment is also reflected in a more technical component during the assessment procedure itself. The transformation of existing datasets (such as statistical data, physical model results) into a unit-less range of values (for example 0–1) or respective classes (zero through to five) that allow for comparison and aggregation in order to describe a situation in a range between optimal and critical, is very demanding. Particularly for larger scale assessments (e.g. at the national level), where value-based decisions become a political issue, there is a relatively low competence and readiness of stakeholders to make such decisions. In the author’s approach the fall-back solution in such cases was a min-max normalisation, which was not completely satisfying due to its pseudo-objectivity, as implicitly it still contained a value-based decision. The value-based aspect also becomes a challenge when a vulnerability assessment needs to be used for monitoring and thus repeated after a certain period of time. Is it possible and valid to maintain the value-based decisions, or should they be adapted to fresh developments?

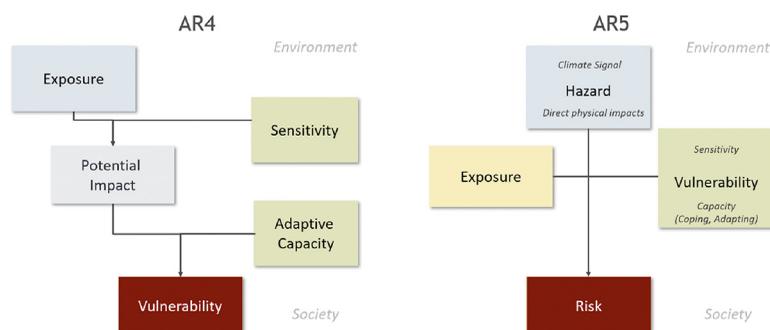
A fourth challenge regarded the interpretability of results at higher levels of aggregation. Whilst the level of understanding and applicability was high at lower levels of aggregation (e.g. assessment of potential impact, assessment of adaptive capacity), the final aggregation step of potential impact and adaptive capacity to vulnerability was less easy to interpret, or even less helpful for adaptation activities. However, the aggregation into climate vulnerability is useful to identify spatial hotspots with high vulnerability, where several factors are in a critical state, and for comparative studies across different regions.

6. Applying the vulnerability sourcebook to the AR5 concept of climate risk

After the publication of the Vulnerability Sourcebook in 2014, the IPCC-AR5 WII report (Field *et al.*, 2014) introduced a new concept of “climate risk”, which is closer to the disaster risk community than the AR4 concept. The Risk Supplement to the Vulnerability Sourcebook (Zebisch *et al.*, 2017) explains how the Sourcebook concept can be applied to the new AR5 climate risk concept.

The AR5 risk concept does not only introduce new terms and new definitions for old terms but follows a slightly different philosophy (Figure 8).

In the AR5 concept, hazard is the potential occurrence of a physical (meteorological or climate) event or trend or physical impact that may cause harm such as: loss of life, injury, negative health impacts, as well as damage and loss of property, infrastructure, livelihoods,



Source: From Zebisch *et al.* (2017)

Figure 8.
Comparison of the
components of
climate change
vulnerability (AR4)
and climate risk
(AR5)

ecosystems and environmental resources. Vulnerability is the predisposition to be adversely affected. Vulnerability (in AR5) encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Exposure is the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure or economic, social, or cultural assets in places and settings that could be adversely affected. Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain [...]. Risk results from the interaction of vulnerability, exposure, and hazard (Field *et al.*, 2014). In the Risk Supplement the authors conclude that the Vulnerability Sourcebook concept with impact chains as its core concept can be applied almost unchanged following the same eight steps and the indicator-based approach. The main modification is to assign factors to AR5 risk components Hazard, Exposure and Vulnerability when building impact chains.

7. Conclusion

It is concluded from the application of the assessment approach in very different settings, that an indicator-based vulnerability assessment building on a systemic approach, which is co-developed and co-performed with the respective stakeholders, is a very useful tool for adaptation planning and monitoring. When developed with care, it can represent the right balance between the demand to “measure” vulnerability and the consideration of the unmeasurable aspects of vulnerability. Challenges include the replicability of the assessment based on data availability, decisions to be made considering non-scientific objectives of political, social, economic or cultural type, the interpretability and comparability of aggregated results. Future developments to improve the approach and to make it more replicable could include a good selection of robust and simple standard assessment approaches and standard impact chains for common climate impacts in the context of developing countries (such as agricultural drought, health issues, sea-level rise), as well as a clearer agreement on the reference of assessment (what does 100% Vulnerability mean?). Furthermore, the relatively linear and sectorial approach of impact chains could be widened to impact webs, which would include feedback relations and cross-connections.

Meanwhile, the “Risk supplement” to the Vulnerability Sourcebook has been published (Zebisch *et al.*, 2017), which transfers the assessment approach with impact chains to the latest IPCC AR5 concept. Another guideline focuses specifically on how to apply the impact chains approach for climate risk assessment within the context of Ecosystem based Adaptation – EbA (Hagenlocher *et al.*, 2018). The Sourcebook approach has been applied in over twenty countries and has been translated into Spanish, French and Arabic. More documents, guidelines and other resources related to the Sourcebook can be found online at AdaptationCommunity.net (Deutsche Gesellschaft für Internationale Zusammenarbeit - GIZ, 2019).

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