

# UNIVERSITY

INSTITUTE FOR ENVIRONMENT AND HUMAN SECURITY (UNU-EHS)

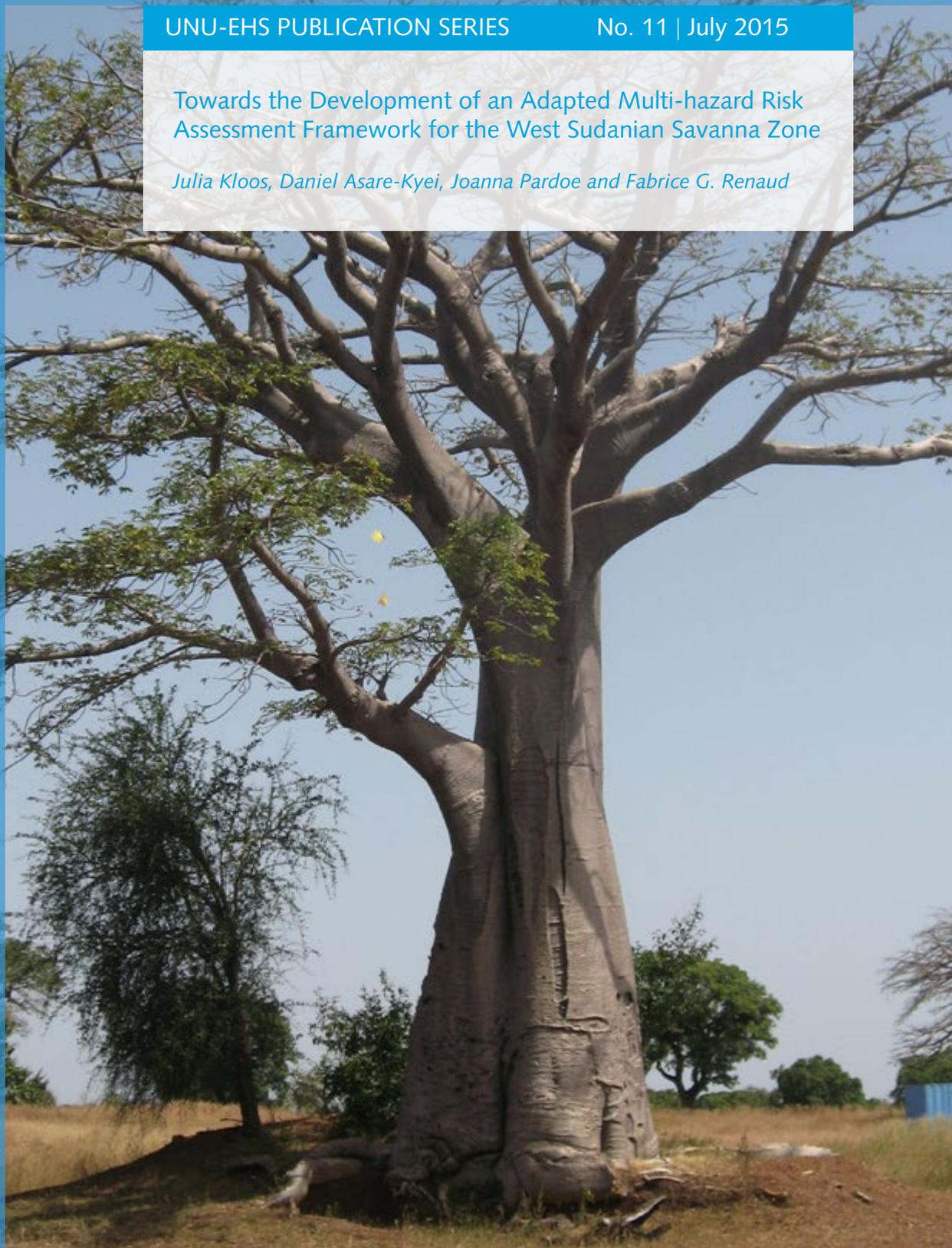
## WORKING PAPER

UNU-EHS PUBLICATION SERIES

No. 11 | July 2015

Towards the Development of an Adapted Multi-hazard Risk Assessment Framework for the West Sudanian Savanna Zone

*Julia Kloos, Daniel Asare-Kyei, Joanna Pardoe and Fabrice G. Renaud*



UNITED NATIONS  
UNIVERSITY

UNU-EHS

SPONSORED BY THE



Federal Ministry  
of Education  
and Research

THROUGH

**WASCAL**  
West African Science Service Center on  
Climate Change and Adapted Land Use

# TOWARDS THE DEVELOPMENT OF AN ADAPTED MULTI-HAZARD RISK ASSESSMENT FRAMEWORK FOR THE WEST SUDANIAN SAVANNA ZONE

## **Abstract**

West Africa is a region considered highly vulnerable to climate change and associated with natural hazards due to interactions of climate change and non-climatic stressors exacerbating the vulnerability of the region, particularly its agricultural system (IPCC, 2014b). Taking the Western Sudanian Savanna as our geographic target area, this paper seeks to develop an integrated risk assessment framework that incorporates resilience as well as multiple hazards concepts, and is applicable to the specific conditions of the target area.

To provide the scientific basis for the framework, the paper will first define the following key terms of risk assessments in a climate change adaptation context: *risk, hazard, exposure, vulnerability, resilience, coping* and *adaptation*. Next, it will discuss the ways in which they are conceptualized and employed in risk, resilience and vulnerability frameworks. When reviewing the literature on existing indicator-based risk assessment for West African Sudanian Savanna zones, it becomes apparent that there is a lack of a systematic and comprehensive risk assessment capturing multiple natural hazards.

The paper suggests an approach for linking resilience and vulnerability in a common framework for risk assessment. It accounts for societal response mechanism through coping, adaptation, disaster risk management and development activities which may foster transformation or persistence of the social ecological systems. Building on the progress made in multi-hazard assessments, the framework is suitable for analyzing multiple-hazard risks and existing interactions at hazard and vulnerability levels. While the framework is well grounded in theories and existing literature, and advances the knowledge by including and linking additional elements, it still remains to be tested empirically.

## **Acknowledgements**

We are grateful for the financial support provided by the German Federal Ministry of Education and Research (BMBF) (Grant no. 01LG1202E) under the auspices of the West African Science Service Centre for Climate Change and Adapted Land Use (WASCAL) project. We are also grateful to the local staff of WASCAL who greatly supported and coordinated the field work. We greatly appreciate the comments made by Dr. Thomas Abeling, UNU-EHS, on the final version of this paper as well as the many initial discussions with Stella Hubert, German Aerospace Center (DLR). We would also like to thank Anastasia Rotenberger, UNU-EHS, for language editing of selected chapters.

The views expressed herein are those of the authors and do not necessarily reflect the views of the United Nations University

## TABLE OF CONTENTS

1. Introduction.....	4
2. Theoretical Concepts .....	5
2.1 Hazards .....	6
2.2 Vulnerability Concepts .....	7
2.2.1 Exposure and Susceptibility.....	7
2.2.2 Coping and Adaptation.....	8
2.2.3 Vulnerability and Vulnerability frameworks .....	8
2.3 Resilience of social-Ecological Systems.....	11
2.3.1 Regimes, tipping points and thresholds.....	11
2.3.2 Adaptability and Transformation.....	12
2.3.3 Measuring resilience and resilience frameworks .....	13
3. Linking Vulnerability and Resilience .....	13
4. Risk Assessment.....	15
4.1 Risk .....	16
4.2 Indicator-based vulnerability and risk assessment.....	16
4.3 Risk Assessment in a Multiple-Hazard context.....	18
5. Prototype of a multi-hazard risk Assessment Framework for the Western Sudanian Savanna Zone.....	20
6. Conclusion and Outlook .....	26
References .....	28

## TABLE OF FIGURES

<b>Figure 1.</b> Prototype of a Multi Risk, Vulnerability and Resilience Assessment Framework for the Western Sudanian Savanna Zone (H: Hazard; Green: „physical/environmental“-related, Red: social system-related), (Source: authors).....	21
<b>Figure 2.</b> Single vs. multi-risk assessment (Source: authors) .....	25

## 1. INTRODUCTION

West Africa is among the most vulnerable regions globally to the effects of climate change. This is because of the high reliance on agriculture, particularly rain-fed agriculture, worsened by numerous biophysical and human related issues in the region including erosive rainfall, variations in the traditional rainfall patterns, recurring drought, soil qualities and fertility, low input farming systems, decreased fallow period, deforestation, frequent bush fires, and overgrazing (USAID, 2011). The region is characterized by a unimodal rainfall regime where, under normal conditions, there is a single rainy season from April to October/ early November, followed by a dry season. Rainfall, the features of the rainy season (onset, dry spells, length of the growing season, etc.), droughts, dry spells and floods are the key influencing factors of food production in the region with often long-term impacts on the social-ecological systems.

Significant dry spells, shorter lengths of the growing season due to late onset and/or early cessation of rain and decrease in total rain all contribute to crop failures and reductions in yields. Climate change portends greater variations in the rainfall patterns and some changes have already been assessed in West Africa (Araya and Stroosnijder, 2011). Laux et al (2008) observed that an earlier onset of the growing season was more common in the past in the Volta basin, while the end of the rainy season appeared to be relatively stable (Laux et al, 2008). In line with this, Neumann et al (2007) found a declining trend in April rainfall since the 1960s. Farmers also reported shifts in the onset of the rainy season, which used to start in April, towards May. These farmers now sow 10–20 days later than their parents (van de Giesen et al, 2010). These assessments suggest a shift in seasonal patterns in West Africa which may persist (Sarr et al, 2012) and future changes in frequency and seasonal distribution of high intensity rainfall events (Sylla et al, 2015), bringing challenges to the agriculture-dependent communities.

Natural hazards such as floods and droughts are recurrent occurrences with varying degrees of impacts in different West African countries. Between 1991 and 2008 Ghana experienced six major floods; the largest number of people affected being in 1991 (NADMO, 2009). In 2007, floods followed immediately after a long period of drought and damaged the initial cereal harvest. This, according to the World Bank (2009), is an indication of high variability in climate and hydrological flows in Northern Ghana. During this flood disaster, at least 20 people died and an estimated 400,000 people were affected, over 90,000 people were displaced and nearly 20,000 homes were damaged (Preventionweb, 2014). Besides floods and droughts, windstorms and thunderstorms can also have severe impacts. Many farmers report of windstorms associated with thunderstorms that are always disastrous (Asare-Kyei et al, 2013). These events do not lead to flooding but often cause houses to collapse and farms to be destroyed.

In Burkina Faso, where annual rainfall has been averaging 1,200mm, as much as 300mm occurred within one hour on 1 September 2009 and the Burkinabe Government estimated costs of US\$152 million to face the consequences of the flooding (IRIN, 2009). Again in 2010, torrential rains caused massive flooding that affected more than 133,000 people in many parts of the country. At least 13 provinces were flooded, with more than 16,000 households directly affected by the floods, and 14 people were reported dead (Reliefweb, 2010a).

Benin was also hit in 2010 by severe flooding when twice the average rainfall amounts occurred. As a result more than 350,000 people were affected and estimated 130,000 hectares of crops lost as reported by Caritas (Reliefweb, 2010b). The Niger river in the North-East of the country floods regularly.

The many structural problems, such as lack of infrastructure and insufficient response capacity and preparedness, coupled with population growth, urbanization and land degradation, are important factors that influence the capacity of West African societies to cope with natural hazards. Within the framework of the West African Science Service Centre for Climate Change and Adapted Land Use (WASCAL) project, which targets climate change mitigation and adaptation measures and aims to enhance the resilience of human-environment systems, a risk assessment in the context of rainfall patterns and climate change would help to better understand these challenges. As both floods and droughts play a major role in West Africa, any risk assessment would need to take a *multi-hazard* approach which includes both a hazard and a vulnerability assessment for multiple hazards. A multi-hazard vulnerability assessment accounts for the hazards and their potential impacts. At the vulnerability level, it is, for instance, essential to understand whether existing coping and adaptation strategies address and reduce vulnerability to several hazards or potentially increase vulnerability to other hazards. Although there are other hazards that affect the West African cases, the focus will be on achieving a multi-hazard risk assessment by initially assessing two of these hazards. As floods and droughts are the most widespread natural hazards in terms of affected people in the West African subregion (Preventionweb, 2014), these will be a focus for developing a method for multi-risk assessment. Once tested and if successful, the method could be applied to other hazards and other places.

In order to develop a multi-hazard risk assessment approach, this paper will provide the theoretical and analytical basis by outlining the key elements of a risk assessment and their conceptualization in a range of existing scientific frameworks (chapter 2). Next, it compares the development and usage of the key theoretical concepts around vulnerability and resilience (chapter 3). This is followed by a review of existing studies on assessing risk and vulnerability which are relevant for the West African subregion and highlights the gaps in the existing literature (chapter 4) before moving on to the development of the conceptual framework that is based on the main findings of the previous chapters (Chapter 5). This paper builds on the existing literature and theory in the field to derive an adapted and integrated risk assessment framework for multiple hazards applicable to the West African context. We will test it using three case study countries, which are located at least partly in the Western Sudanian Savanna zone, namely Ghana, Burkina Faso and Benin to empirically test the framework (WASCAL 2012). Finally, conclusions and an outlook are provided (chapter 6).

## 2. THEORETICAL CONCEPTS

In the social and ecological fields, the literature on natural hazards and risk assessment predominantly revolves around the conceptualization of several key terms. These key terms are *hazard, exposure, vulnerability, resilience, coping* and *adaptation*. Although the terms are used throughout the literature, they are conceptualized and embedded into theoretical frameworks in different ways, particularly reflecting the protracted debate surrounding the use of vulnerability

versus resilience. More recently, however, there have been attempts to draw parallels between these two concepts, recognising how they address different but potentially complementary aspects of hazard management. Increasingly, new perspectives on their conceptualization and how they can be applied to Social-Ecological Systems (SES) that includes societal (human) and ecological (biophysical) subsystems in mutual interaction (Gallopín, 2006) are emerging.

In this section, the intention is not to provide a comprehensive review of the very large amount of literature on these concepts, but rather to discuss the different streams in the literature with reference to their applicability for the intended multi-hazard risk assessment framework. The hazard component is strongly driven by the specific conditions in the West Sudanian Savanna region and therefore we focus on the main hazards flood and droughts and the way they materialize in the study area given our first research findings. Regarding the concepts of exposure, vulnerability and coping and adaptive capacity and resilience not much region-specific literature is available. For these concepts, our discussion remains rather theoretical and conceptual.

The literature around risk assessment bringing together the individual components is then compiled under chapter 4.

## 2.1 HAZARDS

**Hazards**<sup>1</sup> are phenomena of varying spatial extent with the potential to lead to damaging events or disaster that “*may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.*” (IPCC, 2012:32). As described in IPCC (2012), disasters emerge from the interaction of hazards, as physical contributors to disaster risk; exposure and vulnerability, which are both characterized by the link to human or social aspects. Thus, while the physical occurrence of hazards may be unavoidable, preparedness measures and precautionary steps might prevent disasters from happening. **Sudden onset** hazards appear rapidly (flood, earthquake, tsunami etc.), while they can also manifest as **slow onset events** (drought, sea level rise). Slow onset events are often perceived differently by policy makers and the public and it is not until a tipping point is reached that they become disasters (Cutter et al, 2003).

The aim of a hazard assessment is to characterize hazards according to their most important characteristics such as the probability of occurrence or frequency of hazard events, the intensity and the affected area (ISDR, 2004). In the context of this paper, the focus will be on natural hazards, in particular floods and droughts as the main ones. At the local level, droughts can be conceptualized in different ways, depending on the context. In the West Sudanian Savanna, our research shows that droughts are conceptualized depending on their occurrence in relation to the patterns of the rainy season, potentially even as a sequence of drought-related hazards:

1. Late onset of the rainy season (resulting in an extended length of the previous dry season)
2. Several short dry spells or one long dry spell within the rainy season
3. An early ending of the rainy season (initiating an extended length of the following dry season)

---

<sup>1</sup> Important terms and concept of direct relevance for the Multi Risk, Vulnerability and Resilience Assessment Framework are marked as bold when they are introduced in the theoretical chapters.

Similar to droughts, flooding is subject to context specifications at the local level. In the West Sudanian Savanna, flooding usually occurs towards the end of the rainy season when heavy rains take place, but may also occur together with storms at the onset of the rainy season. In the case study areas these floods can be characterized as:

1. Pluvial flooding (heavy rainfall that is unable to infiltrate the ground before causing damage)
2. Fluvial flooding caused by overflowing rivers
3. Groundwater flooding caused rainfall that raises the water table above the ground

Flooding can have a natural origin through excessive rainfall, but may be also aggravated through anthropogenic sources such as the spilling of hydropower dams<sup>2</sup>, absence of land use plans, poor drainage network and land use/conversion.

## 2.2 VULNERABILITY CONCEPTS

Defining the characteristics of vulnerability is an important but contentious subject in the literature due to its use in various streams of research such as hazard assessments and disaster management, livelihoods, poverty, food security and, more recently, climate change (e.g., Birkmann, 2013; Miller et al, 2010). Over time, the conceptualisation of vulnerability has expanded to include social, economic, cultural, environmental and institutional dimensions (Birkmann, 2013). However, it seems new definitions draw on previous definitions and incorporate similar components providing only slight modifications to phrasing and hence not much novelty<sup>3</sup>. Vulnerability is now widely accepted as a dynamic, multi-dimensional, highly context-specific concept that is both socially and spatially differentiated (Adger et al, 2004; O'Brien et al, 2004; e.g., Prowse, 2003) and which still cannot be precisely defined (Birkmann, 2013). The key components of vulnerability that reappear in various definitions are **susceptibility** or sensitivity/ fragility<sup>4</sup>, **exposure**, **coping and adaptive capacity**. These concepts will be briefly discussed in the following sub-sections.

### 2.2.1 EXPOSURE AND SUSCEPTIBILITY

The IPCC (2012) defines exposure *“as the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage”*.

Exposure refers to the physical space upon which a hazard may act and susceptibility refers to the potential for the hazard to affect people and/or property which is linked to the fragility of exposed elements or their predisposition to be adversely affected. Combined, these two components provide the basis for the concept of vulnerability as *“propensity to harm”* (e.g., Füssel, 2009; Turner et al,

---

<sup>2</sup> In 2009 heavy rains in Burkina Faso forced officials to open the main gate of a hydroelectric dam in the Volta River basin, near the Ghanaian border, causing additional flooding in both countries (IRIN News, 2009a).

<sup>3</sup> Numerous reviews have been conducted discussing the evolution of concept definitions, shedding light on complementarities and differences (e.g., Adger, 2006; Birkmann, 2006; Birkmann, 2013; Gallopín, 2006; Miller et al, 2010; Smit and Wandel, 2006).

<sup>4</sup> Susceptibility, sensitivity and fragility are often used interchangeably and capture very similar ideas (e.g. Costa and Kropp 2013). However, as the term sensitivity can be considered as more neutral while susceptibility bears a negative connotation, we follow the argumentation of Birkmann (2013) that susceptibility captures the deficiencies in the system and therefore allows a sharper separation from capacity (coping or adaptive capacity) that describe the capacities systems have to deal with hazards.

2003) or “*potential for change*” when confronted with a stressor (Gallopín, 2006), or “*potential to be adversely affected*” (Birkmann, 2013), recognizing the connection between the spatial extent and nature of the hazard, in addition to the fragility of the structures and society upon which it may act.

Recognising the important role of social processes in mitigating or enhancing the impacts of a hazard, many definitions of vulnerability also include reference to coping, coping capacity, adaptation and adaptive capacity such as McCarthy et al. (2001), Brooks (2003), O’Brien et al. (2004), Füssel and Klein (2006), Füssel (2007), and O’Brien et al. (2008) (all as cited in IPCC, 2012), Adger (2006), Gallopín (2006), Kaspersen et al., (2005) (all as cited in Miller et al., (2010)) and IPCC (2012).

### 2.2.2 COPING AND ADAPTATION

While coping and adaptation have sometimes been used interchangeably, more recently, a clearer definition in the use of the terms has evolved (Birkmann, 2013).

Coping and coping capacity in the vulnerability literature refer to measures (or the potential to initiate measures) that provide for the “*protection of the here and now*” (Birkmann, 2013:196). If a system copes successfully with a hazard, it returns to its “*pre-hazard state*” (Adger et al, 2004:68). Coping capacity, sometimes used synonymously with capacity of response<sup>5</sup> (Gallopín, 2003), is influenced by currently available resources and their usage and determines whether a SES can survive the hazardous impacts relatively intact (Bankoff, 2004; Wisner et al, 2004, as cited in IPCC 2012) and captures actions that aim at the “*conservation of the current system and institutional settings*” (Birkmann, 2011:1117).

Adaptation and adaptive capacity refer to longer-term and more sustained adjustments in order for the system to better cope with, or manage changing conditions, or stresses such as hazard (Gallopín, 2006; Smit and Wandel, 2006). These adjustments tend to mitigate the impact (or potential impacts in case of anticipatory adaptation) of a hazard, whether the hazard has occurred or may occur, and therefore aim at a vulnerability reduction.

While coping focuses more on the short-term, constraint, and immediate survival after a hazard; adapting is oriented towards the future and carries notions of new, beneficial opportunities, emphasizing learning, experimentation and changes (in behavior or structurally) (IPCC 2012). Of course, it is possible for such changes to have a negative impact on vulnerability and thus constitute mal-adaptation and this is recognized in our proposed framework.<sup>6</sup> Adaptation is usually a process that is driven by a number of factors, not only triggered by climate change alone (e.g., Adger et al, 2007) and therefore needs to be understood in the broader context.

### 2.2.3 VULNERABILITY AND VULNERABILITY FRAMEWORKS

---

<sup>5</sup> Capacity of response is the system’s ability to adjust to a disturbance, moderate potential damage, take advantage of opportunities, and cope with the consequences of a transformation that occurs” (Gallopín, 2006) (p. 296)

<sup>6</sup> Similar definitions: Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities (Moser and Ekstrom 2010).

Summarizing the above sections, vulnerability hence describes a condition or a potential condition arising from a system's "*exposure, susceptibility, and coping capacity, shaped by dynamic historical processes, differential entitlements, political economy, and power relations*" (Blaikie et al, 1994; Downing et al, 2005; Eakin and Luers, 2006, as cited in Miller et al. 2010:4), rather than the actual outcome of a stressor or hazard (Gallopín 2006).<sup>7</sup>

Vulnerability may comprise certain factors, such as poverty, and the lack of social networks and social support mechanisms, which make a system vulnerable irrespective of the type of hazard (IPCC 2012). Adger et al. (2004) referred to a complex set of characteristics such as people's wellbeing, livelihoods, degree of self-protection, social, cultural and political networks and institutions. Some researchers suggest to differentiate between hazard-dependent and non-hazard dependent vulnerability conditions (Cardona and Brabat, 2000). The IPCC (2012) assigns high confidence to the finding that exposure and vulnerability are "*dynamic, varying across temporal and spatial scales, and depending on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors*" (IPCC 2012:7).

In lieu of an obvious proxy for vulnerability, there is a considerable challenge for those attempting to measure vulnerability. Many of the factors that influence vulnerability such as the strength of social networks can only be measured indirectly. Additionally, while the components of vulnerability (exposure, susceptibility/sensitivity and (coping, adaptive) capacity) become more clear, Birkmann (2013:64) observe that is still not yet sufficiently established in the literature which vulnerability factors belong to which component.

There are numerous studies that investigate vulnerability in a qualitative way, trying to understand the interplay of different factors, others aim to estimate vulnerability quantitatively with the help of a range of indicators as proxies for different aspects of vulnerability. The intended risk assessment framework needs to be applicable for both streams of research and help to link them up. Qualitative research can for instance provide the grounds for an indicator-based assessment and provide guidance as to which factors belong to which component. Engle (2011) criticizes how the various dynamics and scale interactions are often insufficiently considered when measuring vulnerability but does not provide suggestions for improvement (Birkmann, 2013). While qualitative research is more focused at the local scale but acknowledges scale impact from above, quantitative assessments can help to bridge scales and hence scales and links between them should be covered by an integrated risk assessment framework.

Numerous approaches and frameworks for vulnerability assessments have already been developed based on various schools of thought (see e.g. Birkmann (2013) for an overview) that such an integrated risk assessment framework could be build upon.<sup>8</sup>

A particularly influential vulnerability framework emphasizing the human-environmental system (SES) and linkages and interactions between human and environmental systems at various scales

---

<sup>7</sup> The link between exposure and vulnerability is less rigid in the literature as it is sometimes defined as a sub-component of vulnerability, sometimes as an additional component next to vulnerability (IPCC, 2012; IPCC, 2014a) and sometimes as a hybrid between hazard and vulnerability (Birkmann, 2013).

<sup>8</sup> Besides, comprehensive vulnerability frameworks, guidelines and stepwise approaches have also been suggested to be considered in vulnerability assessments (see e.g., Schröter et al. (2010:576-577)).

was developed by researchers in the field of Sustainability Sciences by Turner et al. 2003a.

Vulnerability, in this framework, comprises exposure, sensitivity and resilience.

In addition, the issue of scale is of utmost importance for vulnerability assessments of SES. Processes operate at a wide variety of scales and are often linked across scales. They can change in their nature and sensitivity to various driving forces and cross-scale interactions, exerting a critical influence on outcomes at a given scale and these interactions can be missed by focusing on a single scale (Kremen et al, 2000). Regardless of the focal scale for the assessment, it is important to recognise that vulnerability is a product of activity across scales (e.g., Fekete et al, 2010 for natural hazards studies; Peterson, 2000 for the climate change literature) and thus the focus should not be exclusive to a single scale, particularly at the local scale. Global and local processes contribute to vulnerability and this should be taken into account within vulnerability assessments. This multi-scalar aspect of vulnerability is reflected throughout the theoretical frameworks, including the key **SUST-model** (Turner et al, 2003), **MOVE** (Birkmann et al, 2013) and **BBC frameworks** (Birkmann, 2006). Turner et al. (2003) stress the need to assess scale issues and factors that are linked across scales and emphasize the growing role of multiple stakeholders at the various scales in vulnerability assessments. However, the SUST framework remains difficult to be applied empirically, particularly in terms of capturing all cross-scale dynamics. The SUST framework also does not establish any relationship with risk nor does it show how it is linked to vulnerability (Damm, 2010).

Damm (2010) produced a modified SUST model, and the term resilience was replaced by capacities to avoid confusion with literature on resilience theory. Damm's modified SUST model differentiates more explicitly between the susceptibility of the social and ecological system and divides capacities into ecosystem robustness of the ecosystem and coping and adaptive capacities mainly associated with the social system. Impact and response is also taken out of the vulnerability environment as vulnerability is considered as a potentiality and not as revealed by actual impacts (Damm, 2010).

The BBC-Framework (Bogardi and Birkmann, 2004; Cardona, 1999) is based on earlier frameworks and is closely targeted to the disaster management literature. It emphasizes the different spheres of vulnerability and the dynamic nature of vulnerability, which is, here, composed of exposure and vulnerable elements along with their coping capacity. While risk is part of the framework, the link between vulnerability and risk remains vague and adaptation is missing.

The MOVE framework is a comprehensive framework, drawing from concepts of vulnerability, resilience, coping and adaptation and earlier frameworks such as the BBC-Framework but also explicitly incorporating risk and risk governance concepts. Vulnerability is composed of exposure, susceptibility/fragility and a lack of resilience. The capacities of the element at risk to adapt, cope or recover are described in the MOVE framework as constituting its resilience. While the MOVE framework acknowledges interactions and coupling processes between the environment and the social system at the hazard level, society and the social systems seem to be in the center of analysis, rather than the social-ecological system.

Essentially, these frameworks emphasize the idea that vulnerability is comprised of exposure, susceptibility and capacities such as coping capacities. These elements are influenced by interactions across scales but the focus of analysis is placed on the local scale. Vulnerability is also considered along with mitigating features such as preparedness or prevention, however, the frameworks treat

these features differently, varying the emphasis placed on them and whether or not they are considered part of vulnerability (as in the SUST model) or more distinct (as in the MOVE and BBC frameworks).

## 2.3 RESILIENCE OF SOCIAL-ECOLOGICAL SYSTEMS

Resilience appears in the frameworks described so far, but it remains often unlinked with the various dimensions of resilience thinking related to SES as for instance brought together by the Resilience Alliance<sup>9</sup>. Therefore, we want to reflect on the resilience concept briefly and highlight the elements and linkages that will be considered in the intended multi-hazard risk assessment framework. The concept of resilience has developed considerably<sup>10</sup> since the seminal paper by Holling (1973) which, within the ecological literature, introduced resilience and is closely linked to concepts of **complex adaptive systems** and the adaptive cycle, as well as panarchy. Folke (2006) provides an overview of the emergence of resilience as a concept to analyze SES and the context in which it has developed and Alexander (2013) provides a more recent review on the meaning and use of resilience over time.

Resilience as understood in the context of SES has three defining characteristics (Berkes et al, 2003:13):

- “The amount of change the system can undergo and still retain the same controls on function and structure
- The degree to which the system is capable of self-organization
- The ability to build and increase the capacity for learning and adaptation”

The IPCC (2014b:5) defines resilience comprehensively as *“the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation”*.

### 2.3.1 REGIMES, TIPPING POINTS AND THRESHOLDS

A key feature of resilience thinking is that change rather than equilibrium is the normal state of SES as complex adaptive systems (Holling, 1973), but that there are still some characteristics and relationships within a system that keep the system in its current configuration. Therefore it is essential that social and ecological systems are understood as coupled, closely related systems, focusing on analyzing the nature and strength of relationships, feedbacks and connectedness. Research has demonstrated that complex social-ecological systems can exist in multiple “stable” states, also called stability domains or domains/basins of attraction (e.g., Berkes et al, 2003). Perturbations such as those arising from large-scale external forces (such as climate) can move the system away from this attractor, but the “stable” states are maintained by interconnections, often also across scales, including internal feedback processes so that they can absorb disturbances. A particular combination of feedbacks is often found to be dominant and determines that the system is able to self-organize into a particular structure and function– this is more recently called “regime”.

---

<sup>9</sup> Resilience Alliance: [www.resalliance.org](http://www.resalliance.org)

<sup>10</sup> Resilience is also used and employed by different schools of thought in different ways. Here we focus only on the conceptualization of resilience for social-ecological systems and as advocated by the Resilience Alliance ([www.resalliance.org](http://www.resalliance.org)).

Regimes and attractors may be more suitable terms than stable states to describe the dynamic and fluctuating nature (Carpenter, 2003). As there are multiple stable states for SES in a so called 'stability landscape' described by state variables, a system can move between these stable states either as smooth transitions or as abrupt transitions.<sup>11</sup>

In the latter case, when conditions change gradually or a shock/perturbation hits the system, the system's internal feedback loops help maintain its current stable state up to a certain point and then the system abruptly flips into a different configuration.

For many SES the threshold-type changes are characteristic. If these thresholds are crossed, changes in internal processes and feedbacks will move the system into a different state/system configuration. Thresholds of variables or potential thresholds can exist within the three domains, i.e., the ecological, economic, and socio-cultural context and at multiple temporal and spatial scales<sup>12</sup>. SESs have multiple interacting thresholds that may cause a regime shift once the tipping point is reached.

As complex systems are characterized by non-linear feedbacks, the state of the system after the flip is hardly predictable, but quite often leads to socially undesirable stable states and new regimes evolve, which have negative impacts on the flows of ecosystem services and human well-being. Low resilience of SES may lead to significant shifts in a system, which can initiate a regime shift<sup>13</sup>. The amount of resilience a system possesses relates to the magnitude of disturbance required to fundamentally disrupt the system causing a dramatic shift to another state of the system, controlled by a different set of processes. Reduced resilience, therefore, increases the vulnerability of a system to smaller disturbances that it could previously cope with.

### 2.3.2 ADAPTABILITY AND TRANSFORMATION

Besides resilience, adaptability and **transformation** are related attributes of SES according to Walker et al. (2004). Adaptability in the context of resilience can be understood mainly as a function of the social system - as the capacity of actors to influence resilience and manage it as a characteristic of the social subsystem of an SES (Walker et al, 2004) and therefore in-line with the adaptation conceptualization as explained earlier. In order to increase resilience, actors can influence the location of thresholds and move them or the system further away, change the ease with which thresholds can be reached or manage cross-scale interactions (Walker et al, 2004). Transformability goes beyond adaptability and describes capacity of the current system to create a fundamentally new system. Transformability plays a role when the existing system becomes undesirable or untenable. When society finds itself trapped in this system, moving out of this basin may not be possible or sufficient and therefore a new stability landscape with different state variables has to be created. Researchers have found that windows of opportunity are often needed, when it comes to transformation. These windows of opportunity are often created by shocks or biophysical or social crises (e.g. food, natural hazards, economic crises), which can then provide opportunities for society to fundamentally change the existing system and try a new one (Stockholm Resilience Center, 2011). There is a certain tension between increasing the resilience of the current system and increasing its

---

<sup>11</sup> For more details, see e.g. Walker et al. 2004.

<sup>12</sup> In the absence of a point-disturbance, gradually changing conditions, e.g., nutrient loading, climate, habitat fragmentation, etc., can surpass threshold levels, triggering an abrupt system response.

<sup>13</sup> A regime shift takes place when the dominant feedbacks change. It often occurs with a rapid non-linear change as the system that when reorganizing leads to a different structure and function (Biggs et al, 2010).

transformability into a new system. Adaptability is an important component to both, increasing resilience and managing for transformation.

### 2.3.3 MEASURING RESILIENCE AND RESILIENCE FRAMEWORKS

Despite the widespread recognition, in terms of the importance of understanding and managing for resilience, there remain many challenges concerning how to operationalize the concept of resilience (Carpenter et al, 2001; Cumming et al, 2005, as cited in Cabell and Oelofse, 2012). Recognizing these difficulties in accurately measuring resilience, some alternative approaches have been developed and applied by numerous studies (Bennett et al, 2005; Carpenter et al, 2006a; Carpenter et al, 2006b; Cutter, 1996; Cutter et al, 2008; Darnhofer et al, 2010, as cited in Cabell and Oelofse, 2012; Davidson et al, 2013; Fletcher et al, 2006; Ifejika Speranza et al, 2014; Resilience Alliance, 2010).

Resilience metrics are challenged by the inherent complexity of understanding a SES and it's the state of the key variables, capturing feedbacks and interactions between key influencing variables, the role of thresholds and the overall goal to manage the system for resilience.

Resilience literature also focuses on institutions, social capital, leadership, learning and how to manage and govern the SES in a sustainable way- it does not end at identifying the degree of resilience but is usually very much targeted towards managing resilience and eventually transformation. Holistic frameworks such as the **Ecosystem Stewardship framework** have emerged, that link resilience, adaptation, transformation and vulnerability and aim for identifying action to i) reduce known stresses, ii) develop pro-active policies that can help navigating changes and iii) avoid traps. There are a number of frameworks that are focusing on Resilience of Social-Ecological Systems, with a special focus on transformation and Sustainability (see Ferguson et al, 2013 for a review).

The resilience frameworks seem to be less prominent than vulnerability frameworks and, differently to the vulnerability frameworks, tend to be more focused on hazard outcomes and mechanisms of recovery or transformation in the aftermath of an event such as a natural hazard. As such, these frameworks lend themselves to practical application to assess the aftermath of hazard events. Empirical applications of these frameworks exist, but more research is needed on the applicability of these frameworks to particular, focused problems.

While the frameworks on transformation go beyond the scope of the intended risk assessment framework, some elements from the ecosystem stewardship framework on the relation between vulnerability and resilience and the outcome of the system dynamics prove useful for the context of the intended multi-hazard risk assessment framework.

## 3. LINKING VULNERABILITY AND RESILIENCE

Both concepts deal with questions of how systems handle disturbances and respond to change and therefore it is important to discuss the relation between these two concepts and their potential contribution to a risk assessment. It is widely cited that the concepts of vulnerability and resilience to natural hazards were initially kept separated by their origins and development in different fields

of study. Resilience concepts are often traced back to natural science disciplines (ecological and engineering resilience) with more recent influences from social scientists (e.g., Berkes and Folke, 1998 as cited in Miller et al. 2010; Berkes et al, 2003) whereas the human focus of vulnerability has developed more through hazard studies, geophysical sciences and social sciences, political ecology in particular (Miller et al, 2010). Increasingly, the two concepts are being drawn together as interdisciplinary and holistic approaches are sought.

Studies have linked vulnerability and resilience in different ways (see e.g., Renaud et al, 2010). Some argue that vulnerability is the flip side of resilience. A social ecological system that loses resilience is getting also more vulnerable to change that previously could be handled (see e.g. (Berkes, 2007; IPCC, 2001)). More generally, resilience and vulnerability can be interpreted as “*the two ends of a spectrum. High levels of vulnerability imply a low resilience, and vice versa*” (Cannon, 2008:10). According to the flip-side approach, risk mitigation strategies, by decreasing vulnerability, would directly contribute to improve resilience in a given system. Gallopin (2006) argues that resilience is not the opposite of vulnerability, but rather a sub-component of the adaptive capacity of the social system as it is related to the response capacity aspects of vulnerability. Turner et al. (2003) use resilience as a one of three subcomponents of vulnerability, by describing a system’s ability to cope, respond and adapt to shocks and stressors, while others differentiate between resistance and resilience more explicitly<sup>14</sup>. Birkmann et al. (2013) distinguish between vulnerability and resilience in the MOVE framework along the lines of vulnerability as a negative trait and coping, adaptation and resilience as positive traits.

The points of convergence for the two concepts within SES are that both concepts focus on the capacity for adaptive action and the response of the system (Gallopin, 2006) to shocks or stresses (Adger, 2006, Renaud et al. 2010).<sup>15</sup> However, efforts to pull the two concepts together (e.g. as recommended by Miller et al. 2010, Birkmann 2006, Adger 2006, Turner 2010 ) continue to produce confusion (Renaud et al., 2010) and face resistance arguing the integration cannot be achieved given their different epistemological backgrounds/histories (Cannon and Müller-Mahn, 2010)<sup>16</sup> or temporal differences (Paton, 2008).

Traditionally, vulnerability analysis focuses on specific hazards but an SES approach allows natural hazards to be considered an internal process of a system, broadening the scope of vulnerability studies and bringing them closer to resilience analysis. Resilience thinking considers a wide range of stresses or perturbations to a system’s resilience including also small and gradual changes. However, resilience also differentiates between general and specified (“*of what, to what*” (Carpenter et al, 2001)) resilience. “General” resilience does not consider any particular kind of disturbance or any

---

<sup>14</sup> For instance, resistance was defined as the ability of physical systems to withstand the stress produced by hazard and resilience, the coping capacity and ability to recover quickly from impacts of disasters according to McIntire (2001) or resistance was described as the “capacity of the system to remain unchanged for an interval of time after the event manifested itself” and the resilience as “the capacity of the system to recover to its state prior to the disaster” and the coping capacity as the combination of resistance and resilience according to Villagràn de Leòn (2006).

<sup>15</sup> See Miller et al. (2010) for a detailed overview of differences and points of convergence between vulnerability and resilience concepts.

<sup>16</sup> Paton (2008) emphasizes the between resilience and vulnerability which act in different phases after an event (readiness, response and recovery) while the former refers to improvements in adaptation and the latter to minimizing disorder (Paton, 2008).

particular aspect of the system that might be affected (Resilience Alliance, 2010:34), hence, increasing general resilience may allow the system to better handle all kinds of shocks, including those presently unforeseen. Uncertainties related to hazard events, exposure and vulnerability in the context of climate change and globalization link concepts to resilience thinking, such as ability to self-organize, learning, and adapting over time, increasingly useful to vulnerability research.

As reviewed by Nelson et al. (2007) vulnerability research usually takes an actor-oriented approach (McLaughlin and Dietz, 2008; Miller et al, 2010; Moser, 2010; Wisner et al, 2004) whereas resilience takes a systems-approach (Walker et al, 2006). Vulnerability research is about how various social groups or elements exposed to shocks are potentially affected and this is measured in terms of differences in susceptibility or sensitivity, and their coping, adaptive capacity or robustness, (resilience). Social, economic and political dynamics and processes are more in the focus of vulnerability research than ecological and biophysical processes which are usually more closely considered in Resilience research by its emphasis on interconnections and feedbacks between the social and ecosystem, different system states and thresholds (Miller et al, 2010). Resilience is more closely aligned with the notion and concepts around ecosystem services and trade-offs while vulnerability research has only relatively recently started to incorporate these streams (Turner II, 2010).

The resilience perspective is to accept changes and stresses as part of the system and to learn how to live with it while vulnerability research tries to identify ways to reduce exposure and susceptibility or increase adaptive capacity. However, there may also be trade-offs between the goals of the two approaches which are maintaining/increasing resilience and reducing vulnerability respectively: As vulnerability research is directed toward the most vulnerable groups within a SES, vulnerability reducing measures targeted at those groups may not necessarily increase resilience of the overall system (Dow et al, 2006; Eakin et al, 2009 as cited in Adger et al. 2009; Plummer and Armitage, 2007). A system perspective can allow researchers to recognize these trades-offs and balance them.

**Vulnerability and resilience conceptualizations and frameworks partly overlap or complement each other** as can be seen in frameworks such as the MOVE, SUST and BBC frameworks or in resilience-based frameworks such as in the ecosystem stewardship framework (Chapin et al. 2009). **The arguments made for combining and converging vulnerability and resilience theory centre on the shared terminology and aim to explore the concepts behind these terms to determine the degree to which it may be possible to integrate vulnerability and resilience theories.** Taking lessons from this work and recognizing the overlapping nature of the key terms outlined above, this paper aims at a framework that is **flexible and sympathetic towards the connections between vulnerability and resilience.**

#### 4. RISK ASSESSMENT

Finally, this section define risks and brings together the before mentioned concepts to measure risk. While focusing on indicator-based vulnerability and risk assessments we give an overview of the existing approaches used to measure and quantify risks as there are multiple ways to do so. For this purpose, we review the literature on existing indicator-based risk/vulnerability assessments which are relevant for our target area, the West African Sudanian Savanna zones. It becomes apparent that

there is a lack of a systematic and comprehensive risk assessment capturing multiple natural hazards and the intended framework is one step towards filling this gap.

#### 4.1 RISK

Based on the terms “hazard” and “vulnerability”, risk can be identified as the product of an interaction between the two factors potentially “*including the probability and magnitude of such consequences (if measurable)*” (Birkmann, 2013:24). The definition of **risk** used by the IPCC (2014:5) is broadened and describes risk as the “*potential for consequences where something of value is at stake and where the outcome is uncertain*”. Risk is a result of the interplay between vulnerability, exposure and hazard.

The aim of any vulnerability assessment is to get in-depth knowledge in the weaknesses and capacities/strengths of a system or element at risk and thus help to develop appropriate risk mitigating measures. The complexity of the concept of vulnerability and risk requires a reduction of the various processes with models or frameworks which are evaluated either quantitatively or qualitatively with a set of indicators. To this end, **indicators** are frequently employed to assess the risk faced by elements and societies exposed to hazards. Risk assessments can be carried out at a range of **spatial scales**. Indicators are being increasingly used to measure vulnerability and to understand the risk patterns of societies at risk from both natural and anthropogenic hazards (Eriksen and Kelly, 2006).

#### 4.2 INDICATOR-BASED VULNERABILITY AND RISK ASSESSMENT

Global or regional level vulnerability assessments are increasingly carried out within climate change research to highlight vulnerability hotspots which are usually presented as particularly vulnerable countries. Over the last decade, major global projects have measured risk and/or vulnerability using indicators and indices at the national level (Birkmann 2007, Birkmann 2013)<sup>17</sup>.

Pelling (2013) provided a review of these approaches and discussed the lessons learned and open questions for large scale risk and vulnerability assessments. Vulnerability was captured in different ways in these approaches. Data on mortality or economic losses was the main variable by some, while others used additionally socio-economic data to capture different or all components of vulnerability. The World risk index (WRI) is composed of 4 sub-indicators, conceptualizing risk as being composed of exposure (including frequency and magnitude of hazards), susceptibility, coping and adaptation, therefore trying to provide - similar to the Americas Indexing project (Cardona, 2005) - a comprehensive vulnerability assessment (Birkmann et al, 2011; Welle et al, 2012; Welle et al, 2013).

Besides these global or regional level approaches, there are a number of targeted indicator based assessments for the African region. The Index of Social Vulnerability to Climate Change for Africa (SVA) by Vincent (2004) aimed at creating an index to assess relative social vulnerability across Africa

---

<sup>17</sup> Examples are the Disaster Risk Index (DRI) (Peduzzi et al, 2009; UNDP/BCPR, 2004), the Americas Indexing programme (Cardona, 2005) for Latin America and the Caribbean, Disaster Risk Hotspots (Dilley et al, 2005), Global Risk Analysis (GRA) published in the Global Assessment Report on Disaster Risk Reduction (P. Peduzzi et al, 2010; United Nations, 2009; United Nations, 2011; United Nations, 2013), and the World Risk Index (WRI) published in the World Risk Report (Birkmann et al, 2011; Welle et al, 2012; Welle et al, 2013).

to water scarcity induced by climate change. The study used five composite sub-indices such as demographic structure, economic well-being and stability, institutional stability and strength of public infrastructure, dependency on natural resources and finally global interconnectivity to develop a theory-driven aggregate index (Vincent, 2004).

The World Development Report in 2010 reviewed two of these major indices—Disaster Risk Index, DRI and the SVA and concluded that these indices created spatial patterns out of tune with development-driven indicators and consistently showed a pattern contradictory to expert knowledge (World Bank, 2010:12).

Also, Asare-Kyei et al. (2015) reported that such poor results could arise from omission of certain salient indicators deemed to be relevant by at risk populations. Moreover, the study cautioned against risk comparison across different countries using the same indicator set and weights. This is because differences in risk perceptions, socio-economic conditions and other heterogeneity in many factors will mean that even the same indicator will invariably be ranked differently by different societies (Asare-Kyei et al, 2015).

Risk assessments particularly in the West African region have been pursued **from single hazard analysis** and in some cases without any defining specific hazard under consideration (Boko et al, 2007; Briguglio, 2009; Challinor et al, 2007; Thornton et al, 2006; World Bank, 2009a; World Bank, 2011). Existing risk analyses in the study tend to concentrate on socio-economic damages (to infrastructure and assets) and loss of lives, but often **did not account for the ecological or biophysical aspect which is closely linked to the social processes**. Other risk assessments have been done in much smaller scales and on decoupled SES (Arnold et al, 2012; IFPRI, 2010; Simonsson, 2005; World Bank, 2009). Moreover, many single hazard risk assessments in the region are pursued from mainly qualitative assessments without linking them to quantitative data. On the global risk assessment, Sub Saharan Africa ranks surprisingly low suggesting lower risks compared to other countries. However, this might be misleading because oftentimes, drought is not included in risk assessments (e.g. DRI in their final analysis) or due to lack of complete impact information. This contributes to an underestimation of potential impacts of natural hazards in the region. Additionally, missing data, non-linear relationships between components of vulnerability or individual factors, measuring livelihood impacts, non economic and non-tangible losses and the balancing of including many input variables and their interpretability in terms of policy recommendations are mentioned by Pelling (2013) as challenges.

Research has found that risk assessment from **both quantitative and qualitative** (social, psychological, ecological) measures is required to deliver a more complete description of risk and risk causation processes (Cardona, 2004; Douglas and Wildavsky, 1982; Weber, 2006; Wisner et al, 2004).

To overcome this situation, a focus on **social ecological systems ensures that the ecological and social dimensions are covered** (Lozoya et al, 2011). Besides focusing on the impacts of the hazards themselves on ecosystems and provision of ecosystem services, conducting a risk assessment for a SES includes assessing the longer-term consequences of the hazards according to their effects on ecosystem services provided and how this affects the population. Therefore identifying the

ecosystem services of the region under study and understanding the main activities of how to use them must be included in the analysis.

### 4.3 RISK ASSESSMENT IN A MULTIPLE-HAZARD CONTEXT

As SES are usually impacted by multiple climate events and, hence, face various risks, natural hazard risk assessments should, therefore, not only consider single hazards but rather **multiple hazards** as well as multiple, integrated processes (Bell and Glade, 2004). For example, the reduction of risks from one hazard may increase risks from other hazards, and thus provide no overall benefit (Finlay and Fell, 1997).

Kappes et al. (2012) observe that while for single hazards numerous studies exist, far fewer studies look at multiple hazards and standardized approaches are hardly available due to the specific challenges of multiple-hazard risk assessments (Kappes et al, 2012:1927). Hazards can influence each other, for instance amplify each other, and methods to characterize vulnerability vary between hazards and therefore make it difficult to homogenize or merge different approaches.

Marzocchi et al. (2009) observed, in the literature, an inhomogeneous use of the terminology when referring to multiple hazards. A slightly different terminology is used in the context of climate change research. IPCC (2012) refers to “**compound (multiple) climate events**” when

- *“two or more extreme events occur simultaneously or successively,*
- *combinations of extreme events with underlying conditions amplify the impact of the events,*
- *Combinations of events that are not themselves extremes but lead to an extreme event or impact when combined” (IPCC 2012:118).*

More generally, Hewitt and Burton (1971) use the term “multiple hazards” to describe several hazards that may take place simultaneously, but may more often follow each other, which affect the same place or the same people in an area. These hazards may have the same underlying driver such as climate change, but the hazards themselves do not necessarily trigger each other. This is the case, for instance, when changes in rainfall variability cause droughts and floods in a region, but the floods and droughts do not affect the likelihood of each other, although they can affect the same people or livelihoods. This type of multiple hazards as defined by Burton (1971) is particularly important in the West African region where the same system (people and ecosystems) are affected by floods and then drought and vice versa in the same crop season. Therefore we use the term multi(ple)-hazard risk assessment in this paper.

Despite the diversity of terms, one relationship can be clearly indentified, namely, in which one hazard triggers another. **Cascading hazards** can be viewed as hazards that are influenced by each other but do not occur simultaneously (Kappes et al, 2012:1935). To further specify the different types of relationships, “**simultaneous**” (**possibly independent**) **hazards** define multiple hazards which act potentially independently of each other but **at the same time affecting the same spatial units or exposed elements**. An example of simultaneous hazards may be a tornado and an earthquake in the same region. These two hazards may affect a place at the same time but the incidence of one of these hazards does not influence the incidence of the other. While in these

cases there are no interrelations at hazard level, there may well be interactions at vulnerability level” (see CLUVA-project, Garcia-Aristizabal and Marzocchi 2012). Reviewing the literature on existing indicator-based risk assessment for West African Sudanian Savanna zones, it becomes apparent that there is a lack of a systematic and comprehensive risk assessment capturing multiple natural hazards

Clearly, where multiple, compound, cascading, simultaneous or combined hazards are present, there is a potential for impacts to be influenced, potentially accumulating. Having been affected by, or coping with, one hazard may change exposure or vulnerability to another one arising at a later point in time. However, it is an unsolved problem that the extent to which multiple hazards influence overall impacts is largely unknown.<sup>18</sup>

The vulnerability perspective in a multi-hazards context refers to:

- Numerous exposed elements (e.g. population, infrastructure, ecosystem services, etc.) with varying degrees of vulnerability to multiple hazards
- Time-dependent vulnerabilities, in which the vulnerability of exposed elements may change with time

As multi-hazard risk evaluation is a relatively new field, many of the existing studies do not explicitly take interactions among different hazards into account but rather aggregate single risk indexes independent from other risks to multi-risk indices (Marzocchi et al, 2009). Several studies concerned with multi-risk assessment have attempted to address the question of multiple, cascading and/or simultaneous hazard impacts. Following completion, these independent assessments of hazards and vulnerability components are often combined into a multi-risk map constituting different layers for the hazards and vulnerability. However, Kappes (2012) emphasized that elements within complex systems are *“interacting (possibly nonlinearly), eventually leading to the occurrence of hazard changes, changes of the system state etc. Within another system state, new and different hazard patterns may emerge that differ from the simple sum of all single hazards”* (Kappes et al, 2012:1934). This leads to a situation where potential ‘multi-risk’ index could be higher than the simple aggregation of single risk indexes.

To conduct a multi-risk assessment in a manner that enables an assessment of all the impacts of all relevant hazards, it is necessary to consider vulnerability specifically in relation to situations where several hazards affect the same household or region. To be able to identify the impacts of interactions and potential cascading effects between hazards at the vulnerability level, this research aims to conduct single hazard as well as a multi-hazard risk assessment.

---

<sup>18</sup> More recently, this multi-hazard perspective was taken up by several research projects such (e.g. NaRas-Natural Hazard Risk Assessment and ARMONIA-Applied Multi-Risk Mapping of Natural Hazards for Impact Assessment, both funded under the European Union’s Sixth Framework Programme of research (FP6) and MATRIX- New Multi-Hazard and Multi-Risk Assessment Methods for Europe, Climate change and Urban Vulnerability in Africa (CLUVA funded under FP7). For a recent comprehensive review of the main applications, approaches and research initiatives in the field of multi-risk assessments, see Garcia -Aristizabal et al. (2012).

Multi-risk assessment requires a careful evaluation of the **interactions between vulnerabilities to different hazards**: Reducing vulnerability to one hazard may increase the vulnerability to another. On the one hand, a multi-hazard perspective focuses on the exposure side of the risk equation, aiming to identify the various hazards that affect a place and consider how interactions between the hazards may influence exposure. For example, if an area is exposed to both earthquake and landslides, the occurrence of an earthquake might also trigger a landslide and risk is therefore greater than simply looking at earthquake or landslides. On the other hand, the multi-hazard vulnerability perspective focuses on the vulnerability component of the risk equation and here a similar approach to the multi-hazard perspective is required whereby vulnerability is considered for multiple hazards and the influence of interactions between multiple hazards on vulnerability is also accounted for.

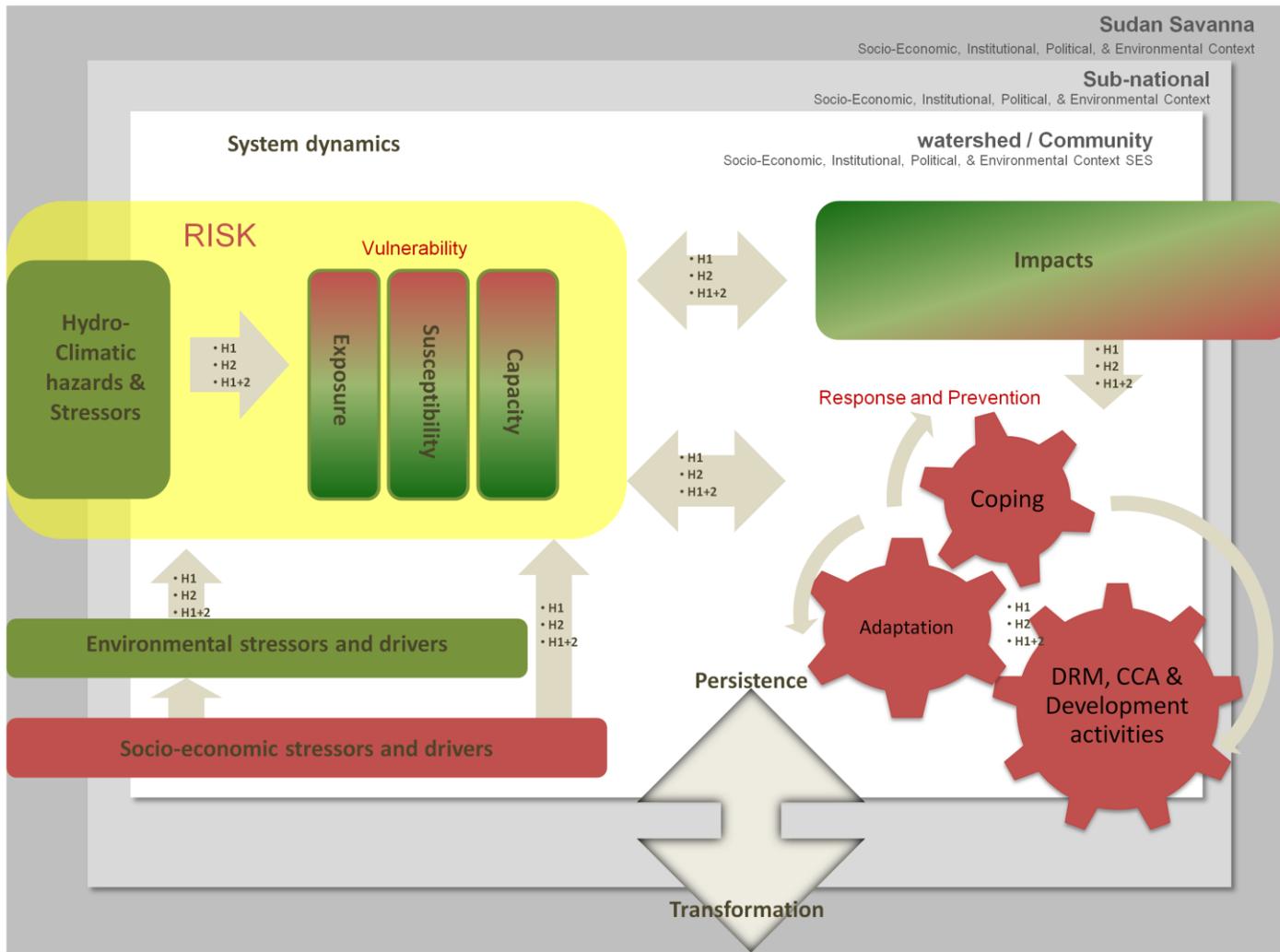
## 5. PROTOTYPE OF A MULTI-HAZARD RISK ASSESSMENT FRAMEWORK FOR THE WESTERN SUDANIAN SAVANNA ZONE

Based on the previously described existing vulnerability, risk and resilience assessment frameworks, a prototype of a spatially explicit risk assessment framework for multiple hazards was developed. We took a **Social-Ecological systems (SES) approach, which recognizes a strong interconnection between the social and ecological systems**, and thus treats the hazard as an internal component of the system, seeing vulnerability as relating directly to the hazard<sup>19</sup>. The framework aims to capture the relationships between **hydro-climatic stressors, shocks and risks, environmental and socio-economic factors/stressors, as well as actual coping and adaptation actions** at multiple **temporal and spatial scales** (see Figure 1). As reflected in the discussion earlier, the existing frameworks all have shortcomings and cannot be directly applied to the West African context. Therefore, we combined elements of the **modified SUST Framework** (Turner et al. 2003, Damm 2010), the **MOVE-framework** (Birkmann et al. 2013)<sup>20</sup>, and the **Ecosystem Stewardship Framework** (Chapin et al. 2010) in order to link vulnerability and resilience in a complementary way and advance these frameworks through an explicit multiple hazard component.

---

<sup>19</sup> In the context of climate change adaptation, the magnitude and frequency of particular hazards are often included in vulnerability to climate change-assessments (Birkmann et al, 2013). Here, we do not include probabilities and frequencies in vulnerability assessments; we only include them in the final risk assessment, which merges the vulnerability and hazard components.

<sup>20</sup> The MOVE-framework itself brings together elements from the following previous concepts and frameworks concepts (Birkmann, 2006; Bogardi and Birkmann, 2004; Cardona, 1999; Carreño et al, 2007; IDEA, 2005; Turner et al, 2003).



**Figure 1.** PROTOTYPE OF A MULTI RISK, VULNERABILITY AND RESILIENCE ASSESSMENT FRAMEWORK FOR THE WESTERN SUDANIAN SAVANNA ZONE (H: Hazard; Green: „physical/environmental“-related, Red: social system-related), (Source: authors)

The framework builds on various elements: the social- ecological system, various temporal and spatial scales, risks, stressors and drivers, multiple hazards, impacts, actions, and finally the persistence or transformation of the SES, all of which will be further explained in more detail.

The framework is centered on a key element, a **social-ecological system**, acknowledging the **interactions and feedback** between the environmental and social sub-systems taking place at various **spatial scales** (local, sub-national and national). The way in which cross scale interactions influence the vulnerability of a SES at a specific locality has been analyzed in the previous vulnerability frameworks (e.g. Cutter, 1996; Turner et al, 2003). Multiple **temporal scales** of the framework's different components have also been examined by looking at the dynamics within the system ("System dynamics"). Furthermore, we emphasized the **dynamic nature of vulnerability**, which can change over time, and of resilience, as the state of an SES is fluctuating in a **basin of attraction**. Both concepts reflect the unstable behavior of **complex adaptive systems**.

Risk is to be evaluated against **hydro-climatic hazards and stressors ("Hydro-climatic hazards and stressors"-box)**, which may materialize as sudden **shocks** in the form of floods and/or heavy rainfall events, **slow onset events** like droughts, and late onset of the rainy season. Risks may also manifest themselves in more **gradual changes** like changes in variability or averages (e.g. within rainfall or temperature). The focus on natural hazards and their links to climate change means that besides considering the **frequency, timing, spatial extent and intensity/severity** of hazards such as flooding or droughts, gradual changes in overall precipitation and/or temperature must also be taken into account as they can slowly undermine resilience. The latter is usually not considered as a hazard according to the above given definitions (see section 2.1), but may still have substantial impacts on people's livelihoods and security in the longer run. Changes in variability and uncertainty, particularly related to seasonal rainfall patterns, may also increase vulnerability or trigger adaptation. Therefore, they are captured as well. Thunderstorms and extreme winds often occur together and with extreme rainfall events, and should be considered as well.

Simultaneously, a SES is affected by **socio-economic drivers and stressors ("Socio-economic drivers and stressors")**, which may lead to environmental changes and consequently transform into hazards. Furthermore, they can compound the impacts of hydro-climatic hazards and stressors, and shape the response capacity of the SES. These impacts can arise from market forces, politics, conflicts, introduction of new policies or governance reforms, changes in institutions, as well as demography and migration. Factors such as perceptions, culture, power and interest characterize the social system and modify how it responds to changes ("Response and Prevention" box). All these factors together dynamically affect the system's internal composition and the response or preventive capacity of different social groups within the SES.

Ecosystem services are an essential component of SES providing numerous monetary and non-monetary benefits to humans. Livelihoods that maintain and use a diversity of provisioning services can be more resilient to hazards since not all provisioning services are equally affected and some can provide alternative food and income sources. Regulating events like drought or flood mitigation, water flows (MA, 2005; TEEB, 2010), or moderating extreme events/disturbance prevention (as

reviewed in TEEB, 2010) can directly influence the vulnerability of SES in different ways. The presence or lack of certain ecosystem services can contribute to a lower or higher exposure of the SES, the availability of multiple ecosystem services can make a system less susceptible, and the availability of the same or other ecosystem services can also increase or decrease the capacity of the SES to deal with hazards.

Socio-economic conditions (e.g. institutions, policies, preferences, perceptions etc.) determine how ecosystem services are managed and governed. Therefore, socio-economic drivers and stressors impact the SES by potentially changing the flow of the ecosystem services. Population pressure and policies fostering agricultural exports, for instance, may require a larger emphasis on provisioning services, which may come at the expense of regulating services (e.g. drought mitigation), or on supporting services (e.g. soil formation). As a result, environmental stressors (“Environmental stressors”-box) like nutrient mining, soil erosion, and ground water depletion triggered by socio-economic conditions affect the risk of the SES.

To account for the **multi-hazard** nature, two hazards (H1” and “H2”) and their combination (“H1+H2”) are introduced to the framework. Though not explicitly mentioned in the framework, more hazards can be added to the analysis, which would increase its complexity. Looking at two hazards simultaneously allows for a separate analysis to account for the interacting effects between the two hazards. It also means going beyond a simple aggregation (addition) of hazard 1 and hazard 2 (see Figure 2). Single hazard analysis is part of the assessment, because not every SES or social group within a SES is affected by multiple natural hazards. Additionally, the interaction effects between hazards (e.g. cascading effects) are also important to analyze (Figure 2).

The analysis guided by this framework aims to identify the mechanisms through which a SES is affected and how differently it responds to **single hazards** H1 and H2 and **multiple hazards** (H1+H2). The reasons for a difference in responses could be due to differences in social groups, various socio-economic characteristics, use and dependency on ecosystem services, physical and institutional frameworks and conditions, policies and political representation, or power constellations leading to different degrees of vulnerability (exposure, susceptibility, and capacities). We used the notions and concepts of exposure, vulnerability, and capacity to measure vulnerability of a SES (“Vulnerability”-box). On its own, the term “vulnerability” means the potential to be harmed or suffer losses. The term is different from the actual impacts related to an event, which can be considered as “revealed” vulnerability. Therefore, “impacts” are not part of the vulnerability box. All elements and connections which comprise a potential or an internal system characteristic are drawn in red or green. An action to respond to or prevent impacts is captured in a grey box. As widely agreed upon in the existing vulnerability frameworks we reviewed, vulnerability is composed of exposure, susceptibility (capturing weaknesses) and capacities (capturing the ability to respond). Following the modification of the SUST-Framework by Damm (2010), the capacity component is comprised of coping capacity and adaptive capacity, which mainly relates to the social system and ecosystem robustness, which, in turn, describes the ecosystem’s capacity to handle disturbance.

Jointly, the three components of vulnerability reflect the extent to which the SES and the social groups within it, ecosystems and ecosystem services, physical infrastructure and assets may potentially be affected by H1 and H2 as well as H1+H2, and how they are all able to deal with them. Risk arises from the combination of vulnerability and the hazards' characteristics: probability, intensity, and extent. Again, as with vulnerability, the term "risk" refers to a potential to be affected, which is usually associated with a certain likelihood and is therefore marked in red. Social groups are typically differentiated based on age and gender but for the West African context, useful social groups can also be differentiated based on different livelihood activities. For example, the activities could be small scale-subsistence agriculture, medium scale and commercial scale agriculture, petty trade activities, as well as those with diverse income sources like teaching, religious work, crafts making, and seasonal immigrant workers.

**The term "impacts"** refers to the direct impacts of hazardous events on the SES, which include damages and losses of infrastructure, as well as people and ecosystem services. "Impacts" can also refer to off-site and indirect effects, which arise at different points in time and space (and can trickle up and down through different scales)<sup>21</sup>. They include actual impacts experienced by the SES, but also anticipated impacts (see the direct link between "vulnerability"-box and "response and prevention"-box). These differently perceived impacts within the SES at various scales might trigger (coping and) adaptation measures taken by the social system. However, they are also shaped by dynamic interactions between ongoing **climate adaptation efforts** and/or **development activities**. Moreover, they are mitigated and feedback into existing Disaster Risk Management.

Development activities are usually not explicitly referred to in vulnerability assessments, but due to the great relevance of such activities for livelihoods and local economies, they are explicitly captured. The coping and adaptation actions induced by the hydro-climatic stressors are influenced by the coping and adaptive capacities of the different social groups, and can also change their susceptibility in the long run. A high coping and adaptive capacity would contribute to lower vulnerability as people have capacities to deal with the changes/impacts in multiple ways.

**The term "adaptation"** broadly covers all strategies or actions taken by individuals or groups within the SES through learning, innovation and experimentation. These strategies can also be promoted by NGOs and the government (in the form of policies). Adaptation refers to all kinds of technological measures and progress, but also social processes or social practices and human institutions that can adapt in the face of climatic triggers (Adger et al, 2009). **Coping** can be divided into erosive and non-erosive strategies. Erosive coping mechanisms mainly describe measures that deplete a household's resources, such as non-productive investments. Non-erosive coping measures include external help, consumption rationing, expenditure reduction, and income diversification. Both coping and adaptation can also be part of Disaster Risk Management (formal and informal), development and/or climate change adaptation programs, and are therefore partly embedded in them within the framework.

---

<sup>21</sup> For instance, cascading effects may also describe such effects, where one impact triggers another impact and total number of impacts may accumulate over time. In this context also, thresholds and tipping points from resilience research become relevant. A resilient system can persist after a change keeping its essential structures and functions within certain threshold ranges. A SES as consisting of several social groups may have several thresholds or eventually tipping points that are crossed when resilience decreases, initiating a regime shift or a transformation (intended or unintended), characterizing a fundamentally new system configuration.

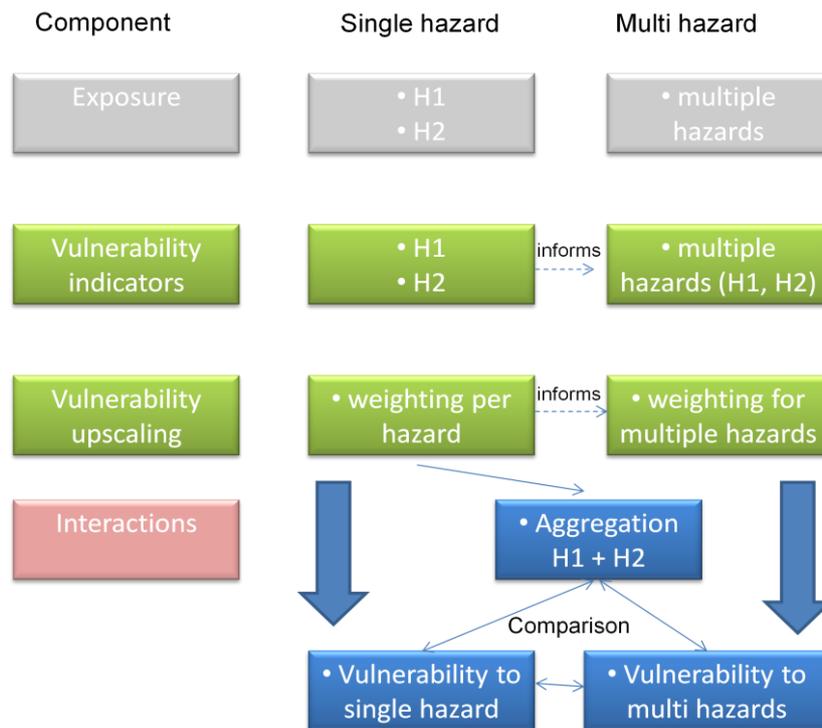


FIGURE 2. SINGLE VS. MULTI-RISK ASSESSMENT (Source: authors)

Here, interaction effects between the different hazards may become particularly relevant as the (real or anticipated) impacts of individual hazards may trigger different coping and adaptation strategies compared to the combined effect of two hazards. Additionally, DRM, CCA and development actions can interfere with coping and adaptation strategies for single or multiple hazards, and facilitate or aggravate individual or informal coping and adaptation. As suggested by Adger et al (2009) multiple values are involved in adaptation decisions. Limits to adaptation actions are contingent on ethics, knowledge, attitudes to risk and culture, and hence endogenous to a society rather than solely dictated by biological/physical, economic or technical parameters, as it is often assumed.

All key concepts need to be considered as dynamic processes. Due to the dynamic nature, feedback processes occur continuously and shape exposure, susceptibility, coping and adaptation capacities, and actions. Coping and adaptation aimed to reduce vulnerability and increase resilience may decrease exposure and increase susceptibility of the SES. However, due to the presence of multiple hazards and interconnected processes, they may also increase vulnerability, and in this case lead to **mal-adaptive and/or erosive responses**. This may further imply that adaptation by the SES is limited, in some way, once climate change and related hazards cross some threshold. Therefore it is essential to assess where these thresholds lie and how far the SES is located.

Finally, depending of the resilience of the SES (or the social sub-groups), the system may **persist**, maintaining its essential functioning and structure in order to (following Folke 2006):

1. Further develop DRM strategies and adapt through learning, innovation and experimentation, leading to decrease in vulnerability to hazards (persistence and development of a desirable system state).

2. Experience certain limits to coping and adaptation, increase vulnerability, and have a trapped status (e.g. persistence of an undesirable system state).

The system may also **transform**, undergoing an essential change in key state variables, functions and structures as:

3. An intended transformation to a system that can better deal with hydro-climatic hazards and stressors leading to a reduced vulnerability (active transformation from an undesirable state to a desirable one).
4. An unintended transformation as the regime shifts by crossing a tipping point when resilience has eroded increasing vulnerability (undesirable state).

## 6. CONCLUSION AND OUTLOOK

This paper presented the following key terms on risk assessment and climate change adaptation: risk, hazard, exposure, vulnerability, resilience, coping and adaptation. Moreover, it discussed the ways in which these terms are conceptualized in risk, resilience, and vulnerability frameworks. Regarding the hazard component, a clarification of its operational definition was provided in this paper. Scientists may work with one definition of hazards while practitioners in the field of disaster risk reduction may work with a different definition. This paper offers an operationalizable definition of hazards under consideration.

Vulnerability is defined by exposure, susceptibility and the capacity of the coupled Social-ecological systems to cope and adapt to the impacts of either a single hazard or the combined effects of multiple hazards. Risk is a product of vulnerability and the characteristics of the hazard. Drawing from existing frameworks in literature on both vulnerability and resilience, an approach for linking resilience and vulnerability in a common framework is suggested. The framework also accounts for societal response mechanism through coping, adaptation, disaster risk management and/or development activities, all of which together lead to transformation, persistence, and affect resilience. Building on the progress made in multi-hazard assessments, where interactions between exposures to more than one hazard are accounted for, the framework is designed to be suitable for analyzing multiple hazard risks by also taking into account interactions at the vulnerability level — something that has been largely neglected to date.

In addition, the framework has also provided a comprehensive overview of the concepts and theories underlying risk and vulnerability assessment in a multi-hazard context, and analyzed the strengths and limitation of the various concepts, frameworks, and existing risk assessments. With a focus on the West African Sudanian Savanna zone during the development of the framework, we want to ensure that we can capture all important elements within SES and identify all the factors that may influence vulnerability, hinder otherwise desirable coping or adaptation strategies, and explain risks.

This framework has been adapted to the conditions in the West Sudanian Savanna, and this prototype will be tested in subsequent studies in order to refine and further adapt it based on the research outcomes. The prototype will be tested against two hazards— floods and droughts— with different manifestations in relation to rainfall patterns. However, it can be extended in the future to include other hazards like epidemics or wildfires as well. The framework will be tested against 3 scales using an indicator-based approach, but can also be adapted to undertake a multi scale risk assessment at basically any scale of relevance.

This context-specific framework allows researchers and practitioners in the region to undertake comprehensive risk and vulnerability assessments critical for strengthening climate change adaptation initiatives. These assessments are meant to mitigate the impacts of climate change, which according to IPCC (2014) are already happening, and are projected to worsen in the coming decades.

## REFERENCES

- Adger, N.W., Brook, N., Bentham, G., Agnew, M., and Erikson, S. (2004), New indicators of vulnerability and adaptive capacity, Technical Report University of East Anglia Norwich NR4 7TJ: Tyndall Centre for Climate Change Research, Norwich.
- Adger, W.N. (2006), 'Vulnerability', *Global Environmental Change* 16, 3, pp. 268–281. DOI: 10.1016/j.gloenvcha.2006.02.006.
- Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., and Takahashi, K. (2007), Assessment of adaptation practices, options, constraints and capacity, in: M. L. Parry, et al. (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK. pp. 717-743.
- Adger, W.N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D.R., Naess, L.O., Wolf, J., and Wreford, A. (2009), 'Are there social limits to adaptation to climate change?', *Climatic Change* 93, 3-4, pp. 335–354. DOI: 10.1007/s10584-008-9520-z.
- Alexander, D.E. (2013), 'Resilience and disaster risk reduction: an etymological journey', *Natural Hazards and Earth System Sciences* 13, pp. 2707-2716.
- Araya, A., and Stroosnijder, L. (2011), 'Assessing drought risk and irrigation need in northern Ethiopia', *Agricultural and Forest Meteorology* 151, pp. 425–436.
- Arnold, G., Carlock, B., Harris, M., Romney, A., Rosa, M., Zollweg, J., Vodacek, A., and Tomaszewski, B. (2012), *Modeling Social Vulnerability in Burkina Faso*, Arc User, Winter 2012 Edition.
- Asare-Kyei, D., Kloos, J., and Renaud, F.G. (2015), 'Multi-scale participatory indicator development approaches for climate change risk assessment in West Africa ', *International Journal of Disaster Risk Reduction* 11, pp. 13-34.
- Asare-Kyei, D.K., Kloos, J., and Renaud, F. (2013), Participatory approaches to develop Indicators for multiple risk assessment linking different scales in West African Social-Ecological Systems under climate change, First ANDROID Residential Doctoral School, 23-24 October 2013, Limassol, Cyprus.
- Bankoff, G. (2004), The historical geography of disaster: “vulnerability” and “local knowledge” in western discourse, in: G. Bankoff, et al. (Eds.), *Mapping Vulnerability: Disasters, Development, and People*, Earthscan, London. pp. 25-36.
- Bell, R., and Glade, T. (2004), Multi-Hazard Analysis in Natural Risk Assessments, in: C. A. Brebbia (Ed.), *International Conference on Computer Simulation Risk Analyses and Hazard Mitigation*. 26.-29. September 2004, Rhodes (GR). pp. 197-206.
- Bennett, E.M., Cumming, G.S., and Peterson, G.D. (2005), 'A systems model approach to determining resilience surrogates for case studies', *Ecosystems* 8, pp. 945–957.
- Berkes, F. (2007), 'Understanding uncertainty and reducing vulnerability: lessons from resilience thinking', *Natural hazards* 41, pp. 283–295.

- Berkes, F., and Folke, C. (1998), *Linking social and ecological systems: Management practices and social mechanisms for building resilience*, Cambridge University Press, Cambridge, UK.
- Berkes, F., Colding, J., and Folke, C. (2003), *Navigating social-ecological systems: building resilience for complexity and change*, Cambridge University Press, Cambridge.
- Biggs, R., Westley, F.R., and Carpenter, S.R. (2010), 'Navigating the back loop: fostering social innovation and transformation in ecosystem management', *Ecology and Society* 15, 2, pp. art. 9.
- Birkmann, J. (2006), Measuring vulnerability to promote disaster-resilient societies: Conceptual frameworks and definitions, in: J. Birkmann (Ed.), *Measuring vulnerability to natural hazards*, United Nations University, New York. pp. 9–54.
- Birkmann, J. (2011), Regulating and Coupling of Society and Nature in the Context of Natural Hazards, in: H. G. Brauch, et al. (Eds.), *Coping with Global Environmental Change, Disasters and Security*, Springer, Berlin. pp. 1103-1127.
- Birkmann, J. (2013), Conceptual Frameworks and Definitions, in: J. Birkmann (Ed.), *Measuring vulnerability to natural hazards*. 2nd edition., United Nations University Press, Tokyo, New York, Paris.
- Birkmann, J., Welle, T., Krause, D., Wolfertz, J., Suarez, D.C., and Setiadi, N. (2011), World Risk Report: Concepts and results, in: A. D. Works (Ed.), *WorldRiskReport 2011*, Berlin. pp. 13-42.
- Birkmann, J., Cardona, O.D., Carreño, M.L., Barbat, A.H., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M., Alexander, D., Zeil, P., and Welle, T. (2013), 'Framing vulnerability, risk and societal responses: the MOVE framework', *Natural Hazards* 67, 2, pp. 193–211. DOI: 10.1007/s11069-013-0558-5.
- Blaikie, P., Cannon, T., Davis, I., and Wisner, B. (1994), *At Risk: Natural Hazards, People's Vulnerability and Disasters*, Routledge, London.
- Bogardi, J., and Birkmann, J. (2004), Vulnerability Assessment: The First Step Towards Sustainable Risk Reduction, in: D. Malzahn and T. Plapp (Eds.), *Disasters and society - from hazard assessment to risk reduction*, Logos-Verl, Berlin. pp. 75–82.
- Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., and Yanda, P. (2007), *Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge UK.
- Briguglio, L.P. (2009), 'Defining and assessing the risk of being harmed by Climate Change', *Harmed by climate change* 23, pp. DOI: 10.1108/17568691011020238.
- Brooks, N. (2003), *Vulnerability, risk and adaptation: A conceptual framework*. Tyndall Centre Working Paper No. 38, Tyndall Centre for Climate Change Research, Norwich.
- Cannon, T. (2008), *Reducing People 's Vulnerability to Natural Hazards Communities and Resilience*, UNU World Institute for Development Economics Research (UNU-WIDER), Helsinki.

- Cannon, T., and Müller-Mahn, D. (2010), 'Vulnerability, resilience and development discourses in context of climate change', *Natural Hazards* 55, pp. 621-635.
- Cardona, O.D. (1999), Environmental Management and Disaster Prevention: Two Related Topics: A Holistic Risk Assessment and Management Approach, in: J. Ingleton (Ed.), *Natural Disaster Management*, TudorRose, London.
- Cardona, O.D. (2004), The Need for Rethinking the Concepts of Vulnerability and Risk from a Holistic Perspective: a Necessary Review and Criticism for Effective Risk Management, in: G. Bankoff, et al. (Eds.), *Mapping Vulnerability: Disasters, Development and People*, Earthscan Publishers, London. pp. 37-51.
- Cardona, O.D. (2005), *Indicators of Disaster Risk and Risk Management: Program for Latin America and the Caribbean – Summary Report*, Inter-American Development Bank, Washington, D.C.
- Cardona, O.D., and Brabat, A.H. (2000), *El Riesgo Sismico y su Prevencion*, Cuaderno Técnico 5, Calidad Siderúrgica, Madrid.
- Carpenter, S. (2003), 'Regime shifts in lake ecosystems: Pattern and variation', *Excellence in Ecology Series*, 15, pp.
- Carpenter, S., Walker, B., Anderies, J.M., and Abel, N. (2001), 'From metaphor to measurement: Resilience of what to what? ', *Ecosystems* 4, 8, pp. 765-781. DOI: <http://dx.doi.org/http://dx.doi.org/10.1007/s10021-001-0045-9>.
- Carpenter, S.R., Bennett, E.M., and Peterson, G.D. (2006a), 'Scenarios for ecosystem services: an overview', *Ecology and Society* 11, 1, pp. 29.
- Carpenter, S.R., DeFries, R., Dietz, T., Mooney, H.A., Polasky, S., Reid, W.V., and Scholes, R.J. (2006b), 'Millenium ecosystem assessment: research needs', *Science* 314, pp. 257–258.
- Carreño, M.L., Cardona, O.D., and Brabat, A.H. (2007), 'Urban seismic risk Evaluation: A holistic approach', *Journal of Natural Hazards* 40, 1, pp. 137-172.
- Challinor, A., Wheeler, T., Garforth, C., Craufurd, P., and Kassam, A. (2007), 'Assessing the vulnerability of food crop systems in Africa to climate change', *Climatic Change* 83, 3, pp. 381-399.
- Cumming, G.S., Barnes, G., Perz, S., Schmink, M., Sieving, K.E., Southworth, J., Binford, M., Holt, R.D., Stickler, C., and Van Holt, T. (2005), 'An exploratory framework for the empirical measurement of resilience', *Ecosystems* 8, pp. 975–987.
- Cutter, S.L. (1996), 'Vulnerability to environmental hazards', *Progress in Human Geography* 20, pp. 529-539.
- Cutter, S.L., Boruff, B.J., and Shirley, W.L. (2003), 'Social Vulnerability to Environmental Hazards ', *Social Science Quarterly* 84, 2, pp. 242-261.
- Cutter, S.L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., and Webb, J. (2008), 'A place-based model for understanding community resilience to natural disasters', *Global Enviromental Change* 18, pp. 698-606.

- Damm, M. (2010), Mapping Social-Ecological Vulnerability to Flooding. A sub-national approach for Germany, Rheinischen Friedrich-Wilhelms University of Bonn, United Nations University-EHS, Bonn.
- Darnhofer, I., Bellon, S., Dedieu, B., and Milestad, R. (2010), 'Adaptiveness to enhance the sustainability of farming systems: a review', *Agronomy for Sustainable Development* 30, 3, pp. 545-555.
- Davidson, J.L., van Putten, I.E., Leith, P., Nursey-Bray, N., Madin, E.M., and Holbrook, N.J. (2013), 'Toward operationalizing resilience concepts in Australian marine sectors coping with climate change', *Ecology and Society* 18, 3, pp. 4. DOI: <http://dx.doi.org/10.5751/ES-05607-180304>.
- Dilley, M., Chen, R.S., Deichmann, U., Lerner-Lam, A.L., Arnold, M., Agwe, J., Buys, P., Kjekstad, O., Lyon, B., and Yetman, G. (2005), *Natural Disaster Hotspots: A Global Risk Analysis*, The World Bank, Washington, D.C.
- Douglas, M., and Wildavsky, A. (1982), *Risk and Culture: An Essay on the Selection of Technical and Environmental Dangers*.  
CA., University of California Press,, Berkeley.
- Dow, K., Kaspersen, R.E., and Bohn, M. (2006), Exploring the social justice implications of adaptation and vulnerability, in: W. N. Adger, et al. (Eds.), *Fairness in Adaptation to Climate Change*, The MIT Press, Cambridge MA. pp. 79-96.
- Downing, T.E., Aerts, J., Soussan, J., Barthelemy, O., Bharwani, S., Ionescu, C., Hinkel, J., Klein, R.J.T., Mata, L.J., Martin, N., Moss, S., Purkey, D., and Ziervogel, G. (2005), *Integrating social vulnerability into water management.*, Stockholm Environment Institute, Oxford, UK.
- Eakin, H., and Luers, A.L. (2006), 'Assessing the vulnerability of social-environmental systems', *Annual Review of Environment and Resources* 31, pp. 365-94.
- Eakin, H., Winkels, A., and Sendzimir, J. (2009), 'Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems', *Environmental Science & Policy* 12, 4, pp. 398-412.
- Engle, N.L. (2011), 'Adaptive capacity and its assessment', *Global Environmental Change* 21, pp. 647–656.
- Eriksen, S.H., and Kelly, P.M. (2006), 'Developing Credible Vulnerability Indicators for Climate Adaptation Policy Assessment', *Mitigation and Adaptation Strategies for Global Change* 12, 4, pp. 495-524.
- Fekete, A., Damm, M., and Birkmann, J. (2010), 'Scales as a challenge for vulnerability assessment', *Natural Hazards* 55, pp. 729–747.
- Ferguson, B.C., Brown, R.R., and Deletic, A. (2013), 'Diagnosing transformative change in urban water systems: Theories and frameworks', *Global Environmental Change* 23, pp. 264-280.

- Finlay, P.J., and Fell, R. (1997), 'Landslides: risk perception and acceptance', *Canadian Geotechnical Journal* 34, 2, pp. 169–188. DOI: 10.1139/t96-108.
- Fletcher, C.S., Miller, C., and Hilbert, D.W. (2006), Operationalizing resilience in Australian and New Zealand agroecosystems, Proceedings of the 50th Annual Meeting of the ISSS, ISSS 2006 Papers.
- Folke, C. (2006), 'Resilience: The emergence of a perspective for social–ecological systems analyses', *Global Environmental Change* 16, 3, pp. 253–267. DOI: 10.1016/j.gloenvcha.2006.04.002.
- Füssel, H.-M. (2007), 'Vulnerability: A generally applicable conceptual framework for climate change research', *Global Environmental Change* 17, 2, pp. 155–167. DOI: 10.1016/j.gloenvcha.2006.05.002.
- Füssel, H.-M. (2009), Background note to the World Development Report 2010: Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity, and impacts.
- Füssel, H.-M., and Klein, R.J.T. (2006), 'Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking', *Climatic Change* 75, 3, pp. 301-329.
- Gallopín, G.C. (2003), *Box 1. A systemic synthesis of the relations between vulnerability, hazard, exposure and impact, aimed at policy identification*, ECLAC, LC/MEX/G.S., Mexico, D.F.
- Gallopín, G.C. (2006), 'Linkages between vulnerability, resilience, and adaptive capacity', *Global Environmental Change* 16, 3, pp. 293–303. DOI: 10.1016/j.gloenvcha.2006.02.004.
- García-Aristizabal, A., and Marzocchi, W.W. (2012), *State-of-the-art in multi-risk assessment*
- Hewitt, K., and Burton, I. (1971), *Hazardousness of a place: a regional ecology of damaging events*, Toronto Press, Toronto.
- Holling, C.S. (1973), 'Resilience and stability of ecological systems', *Annual Review of Ecology and Systematics* 4, pp. 1-23.
- IDEA (2005), *Indicators of disaster risk and risk management—main technical report*, National University of Colombia/Manizales, Institute of Environmental Studies/IDEA and Inter-American Development Bank.
- Ifejika Speranza, C., Wiesmann, U., and Rist, S. (2014), 'An indicator framework for assessing livelihood resilience in the context of social–ecological dynamics', *Global Environmental Change* 28, pp. 109-119.
- IFPRI (2010), *Assessing the Vulnerability of Agriculture to Climate Change in Sub-Saharan Africa*, International Food Policy Research Institute.
- IPCC (2001), *IPCC Third Assessment Report: Climate Change 2001 (TAR)*, Intergovernmental Panel on Climate Change.

- IPCC (2012), *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.
- IPCC (2014a), *Summary for Policy makers Working group II Contribution to the fifth Assessment report of the Intergovernmental Panel on Climate Change*, IPCC.
- IPCC (2014b), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report: Africa Regional Context*, IPCC Secretariat, Geneva, Switzerland.
- IRIN (2009), BURKINA FASO-GHANA: One country's dam, another's flood, Humanitarian news and analysis.
- ISDR (2004), *Living with risk: A global review of disaster reduction initiatives*, 2004 ed., United Nations, New York.
- Kappes, M.S., Keiler, M., von Elverfeldt, K., and Glade, T. (2012), 'Challenges of analyzing multi-hazard risk: a review', *Natural Hazards* 64, pp. 1925-1958.
- Kasperson, R.E., Dow, K., Archer, E.R.M., Cáceres, D., Downing, T.E., Elmqvist, T., Eriksen, S., Folke, C., Han, G., Iyengar, K., Vogel, C., Wilson, K.A., and Ziervogel, G. (2005), Chapter 6: Vulnerable people and places, in: R. Hassan, et al. (Eds.), *Ecosystems and human well-being: current state and trends assessment. Millennium Ecosystem Assessment*, Island Press, Washington, D.C.
- Kremen, C., Niles, J.O., Balton, M.G., Daily, G.C.E., Ehrlich, P.R., Fay, J.P., Grewal, D., and Guillery, R.P. (2000), 'Economic incentives for rain forest conservation across scales', *Science* 288, pp. 1828–1831.
- Laux, P., Kunstmann, H., and Bárdossy, A. (2008), 'Predicting the regional onset of the rainy season in West Africa', *International Journal of Climatology* 28, pp. 329-342.
- Lozoya, J.P., Sardá, R., and Jiménez, J.A. (2011), 'A methodological framework for multi-hazard risk assessment in beaches', *Environmental Science & Policy* 14, 6, pp. 685–696. DOI: 10.1016/j.envsci.2011.05.002.
- MA (2005), *Millenium Ecosystem Assessment*, Island Press, Washington, DC.
- Marzocchi, W., Mastellone, M., and Di Ruocco, A. (2009), *Principles of multi-risk assessment: interactions amongst natural and man-induced risks*, online at: <http://www.scribd.com/doc/16902233/Principles-of-MultiRisk-Assessment>.
- McCarthy, J.J., Canziani, O.F., N.A., L., Dokken, D.J., and White, K.S. (2001), *Climate Change 2001: Impacts, Adaptation & Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press, Cambridge
- McLaughlin, P., and Dietz, T. (2008), 'Structure, agency and environment: Toward an integrated perspective on vulnerability', *Global Environmental Change* 18, 1, pp. 99–111. DOI: 10.1016/j.gloenvcha.2007.05.003.

- Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bahrwani, S., Ziervogel, G., Walker, B., Birkmann, J., van der Leuw, S., Rockström, J., Hinkel, J., Downing, T., Folke, C., and Nelson, D. (2010), 'Resilience and Vulnerability: Complementary or Conflicting Concepts?', *Ecology and Society* 15, 3, pp. 11.
- Moser, S.C. (2010), 'Now more than ever: The need for more societally relevant research on vulnerability and adaptation to climate change', *Applied Geography* 30, pp. 464-474.
- Nelson, D., Adger, W.N., and Brown, K. (2007), 'Adaptation to environmental change: contributions of a resilience framework', *Annual Review of Environment and Resources* 32, pp. 395-419.
- Neumann, R., Jung, G., Laux, P., and Kunstmann, H. (2007), 'Climate trends of temperature, precipitation and river discharge in the Volta Basin of West Africa', *International Journal of River Basin Management* 5, pp. 17-30.
- O'Brien, K., Eriksen, S., Schjolen, A., and Nygaard, L. (2004), What's in a word?: Conflicting interpretations of vulnerability in climate change research, CICERO Working Paper, Oslo.
- O'Brien, G., O'Keefe, P., Meena, H., Rose, J., and Wilson, L. (2008), 'Climate adaptation from a poverty perspective.', *Climate Policy* 8, 2, pp. 194-201.
- P. Peduzzi, P., Chatenoux, B., Dao, H., De Bono, A., Deichmann, U., Giuliani, G., Herold, C., Kalsnes, B., Kluser, S., Løvholt, F., Lyon, B., Maskrey, A., Mouton, F., Nadim, F., and Smebye, H. (2010), The Global Risk Analysis for the 2009 Global Assessment Report on Disaster Risk Reduction International Disaster and Risk Conference IDRC, 30 May 2010, Davos.
- Paton, D. (2008), Community Resilience: Integrating Individual, Community and Societal Perspective, in: K. Gow, Paton, D. (Ed.), *The Phoenix of Natural Disasters: Community Resilience*, Nova Science Publishers Inc.
- Peduzzi, P., Dao, H., Herold, C., and Mouton, F. (2009), 'Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index', *Natural Hazards and Earth System Sciences* 9, pp. 1149-1159. DOI: 10.5194/nhess-9-1149-2009.
- Pelling, M. (2013), Review of global risk index projects, in: J. Birkmann (Ed.), *Measuring vulnerability to natural hazards*. 2nd edition., United Nations University Press, Tokyo, New York, Paris.
- Peterson, G.D. (2000), 'Scaling ecological dynamics: self-organization, hierarchical structure and ecological resilience', *Climatic Change* 44, 3, pp. 291-309.
- Plummer, R., and Armitage, D. (2007), 'A resilience-based framework for evaluating adaptive co-management: Linking ecology, economics and society in a complex world', *Ecological Economics* 61, 1, pp. 62-74. DOI: 10.1016/j.ecolecon.2006.09.025.
- Preventionweb (2014), Burkina Faso - Disaster Statistics, Benin - Disaster Statistics, Ghana - Disaster Statistics. <http://www.preventionweb.net/english/countries>.
- Prowse, M. (2003), Towards a clearer understanding of 'vulnerability' in relation to chronic poverty, CPRC Working Paper No 24, Chronic Poverty Research Centre, Manchester.

- Reliefweb (2010a), Burkina Faso: Floods Emergency appeal no. MDRB010, Reliefweb. Report from International Federation of Red Cross And Red Crescent Societies
- Reliefweb (2010b), We haven't really seen anything like this before": Benin hit by floods.
- Renaud, F.G., Birkmann, J., Damm, M., and Gallopín, G.C. (2010), 'Understanding multiple thresholds of coupled social–ecological systems exposed to natural hazards as external shocks', *Natural Hazards* 55, 3, pp. 749–763. DOI: 10.1007/s11069-010-9505-x.
- Resilience Alliance (2010), *Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners*, Version 2 ed., online at: Online: <http://www.resalliance.org/3871.php>.
- Sarr, B., Atta, S., and Luc, K. (2012), 'Revue des indices climatiques utilisés dans les systèmes d'assurances agricoles indicielles en Afrique', *Revue Sécheresse* 23, 4, pp. 255–260.
- Schröter, D., Polsky, C., and Patt, A. (2010), 'Assessing vulnerabilities to the effects of global change: an eight step approach', *Mitigation and Adaptation Strategies for Global Change* 10, pp. 573–596.
- Simonsson, L. (2005), *Vulnerability Profile of Burkina Faso.*, Stockholm Environment Institute (SEI), Stockholm, Sweden.
- Smit, B., and Wandel, J. (2006), 'Adaptation, adaptive capacity and vulnerability', *Global Environmental Change* 16, 3, pp. 282–292. DOI: 10.1016/j.gloenvcha.2006.03.008.
- Stockholm Resilience Center (2011), *Resilience thinking can help us understand how to initiate and navigate large-scale transformations in social-ecological systems.*
- Sylla, M., Giorgi, F., Pal, J., Gibba, P., Kebe, I., and Nikiema, M. (2015), 'Projected Changes in the Annual Cycle of High Intensity Precipitation Events over West Africa for the Late 21st Century', *Journal of Climate* in press, pp. DOI: 10.1175/JCLI-D-14-00854.1.
- TEEB (2010), *The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations*, Earthscan, London and Washington.
- Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Kristjanson, P., Notenbaert, A., Bekele, N., and Omolo, A. (2006), *Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development*, ILRI, PO Box 30709, Nairobi 00100, Kenya.
- Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., and Schiller, A. (2003), 'Science and Technology for Sustainable Development Special Feature: A framework for vulnerability analysis in sustainability science', *Proceedings of the National Academy of Sciences* 100, 14, pp. 8074–8079. DOI: 10.1073/pnas.1231335100.
- Turner II, B.L. (2010), 'Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science?', *Global Environmental Change* 20, pp. 570–576. DOI: 10.1016/j.gloenvcha.2010.07.003.
- UNDP/BCPR (2004), *A Global Report: Reducing Disaster Risk, A Challenge for Development*, United Nations Development Programme, Bureau for Crisis Prevention and Recovery New York.

- United Nations (2009), *Global Assessment Report on Disaster Risk Reduction. risk and poverty in a changing climate* United Nations, Geneva.
- United Nations (2011), *Global Assessment Report on Disaster Risk Reduction. revealing risk, redefining development* United Nations, Geneva, online at: <http://www.preventionweb.net/english/hyogo/gar/2011/en/home/index.html>.
- United Nations (2013), *Global Assessment Report on Disaster Risk Reduction 2013. From Shared Risk to Shared Value: the Business Case for Disaster Risk Reduction*.
- van de Giesen, N., Liebe, J., and Jung, G. (2010), 'Adapting to climate change in the Volta Basin, West Africa', *Current Science* 98, 8, pp. 1033-1037.
- Villagrán De León, J.C. (2006), Vulnerability: A conceptual and methodological review, SOURCE, UNU Institute for Environment and Human Security (UNU-EHS), Bonn.
- Vincent, K. (2004), *Creating an index of social vulnerability to climate change for Africa*, Tyndall Consortium.
- Walker, B., Holling, C., Carpenter, S., and Kinzig, A. (2004), 'Resilience, Adaptability and Transformability in Social–ecological Systems', *Ecology and Society* 9, 2, pp.
- Walker, B.H., Anderies, J.M., Kinzig, A.P., and Ryan, P. (2006), 'Exploring Resilience in Social-Ecological Systems Through Comparative Studies and Theory Development: Introduction to the Special Issue', *Ecology and Society* 11, 1, pp. 12.
- Weber, E.U. (2006), 'Experience-based and description-based perceptions of long-term risk: why global warming does not scare us (yet)', *Climatic Change* 77, pp. 103-120.
- Welle, T., Birkmann, J., Rhyner, J., Witting, M., and Wolfertz, J. (2012), World Risk Index 2012: Concept, Updating and results, WorldRiskReport 2012, Alliance Development Works, Berlin. pp. 11-26.
- Welle, T., Birkmann, J., Rhyner, J., Witting, M., and Wolfertz, J. (2013), World Risk Index, WorldRiskReport 2012, Alliance Development Works, Berlin. pp. 45-56.
- Wisner, B., Blaikie, P., Cannon, T., and Davis, I. (2004), *At Risk: Natural hazards, People's Vulnerability and Disasters*, Routledge, London.
- World Bank (2009), *Disaster risk management programs for priority countries*, GFDRR. The World Bank, Washington, DC, USA.
- World Bank (2009a), *Disaster risk management programs for priority countries*, World Bank, GFDRR Secretariat, 1818 H Street NW, Washington, DC 20433, USA.
- World Bank (2010), *Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity and impacts: World Development Report 2010: Development and Climate Change*, The World Bank, Washington, DC.

World Bank (2011), *Vulnerability, Risk Reduction and Adaptation to Climate Change: Climate risk and adaptation country profile, Ghana*, Global Facility for Disaster Reduction and Recovery, Washinton, DC 20433, USA.