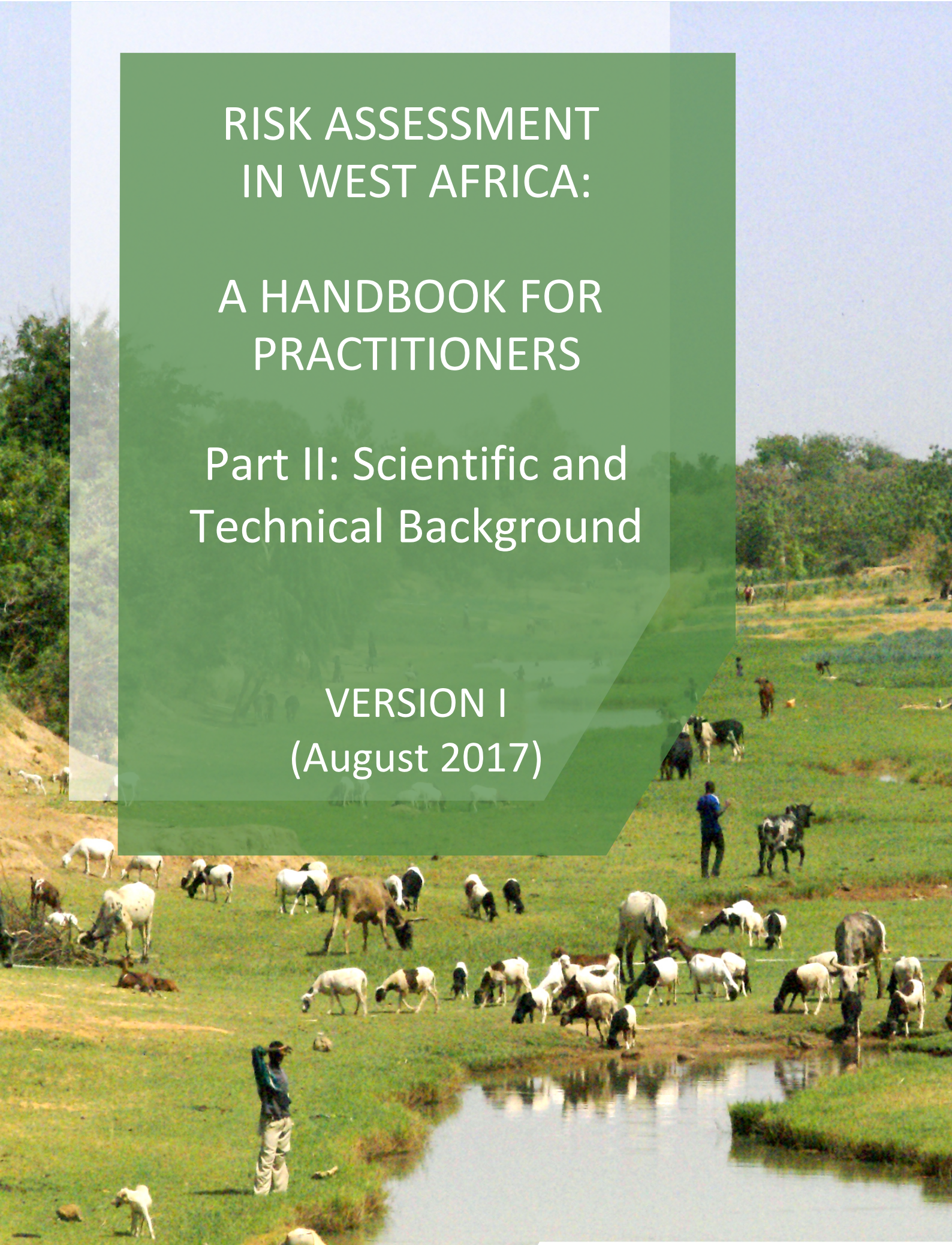
RISK ASSESSMENT IN WEST AFRICA:

A HANDBOOK FOR PRACTITIONERS

Part II: Scientific and Technical Background

VERSION I
(August 2017)



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

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Scientific Background and Technical Guides: Assessing Vulnerability and Risk to Climate-related Hazards

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General Introduction

West Africa is known to be particularly vulnerable to climate change due to high climate variability, high reliance on rainfed agriculture, and limited economic and institutional capacity to respond to climate variability and change (Sultan and Gaetani 2016). Within the Sudanian Savanna recurrent droughts and the overflow of major river systems lead to significant damages to livelihoods, housing, infrastructure and health. For example, in 2007, anomalous rainfall events with return periods of several decades caused severe floods in West Africa that affected more than 1.5 million people, destroyed farm lands as well as infrastructure and triggered the outbreak of epidemic diseases (News Africa, 2007; Levinson and Lawrimore, 2008; Armah et al., 2011; Paeth et al., 2011; Braman et al., 2013). Similar floods in 2009 affected an estimated 600 000 people in 16 West African countries (Di Baldassarre et al., 2010)and in 2012 severe flooding triggered the regions third biggest food crisis in the last seven years (Cornforth, 2013). . When comparing Ghana, Benin and Burkina Faso, Burkina Faso is the most drought prone country and during the past two decades major events occurred in 1990, 1995, 1998, 2001, 2011 and 2014 while affecting between 20,700 and 4,000,000 people. Among those droughts the event in 2014 was the most disastrous (Centre for Research of the Epidemiology of Disasters, 2017).

In order to investigate the vulnerability to floods and droughts, three different case study areas were selected under the WASCAL research program: Dano in Burkina Faso, Dassari in Benin and Bolgatanga in Ghana. They cover an area of 634, 657 and 1038 km2, respectively (Asare-Kyei, 2017). The three watersheds are located within the same climate zone and are characterized by a high degree of similarity across all aspects of life and hazard exposure, but there are subtle differences that influence vulnerability as and therefore overall impacts from hazards.

Within all case study areas, rainfed subsistence- agriculture provides the main source of livelihood, and most alternative sources of income relate to the trade of processed farm products. Even though, alternative occupations such as tailoring, hairdressing services, the production and sale of local beer and security guard services exist (Pardoe, 2016). The main crops that are grown are sorghum, millet, rice and maize,

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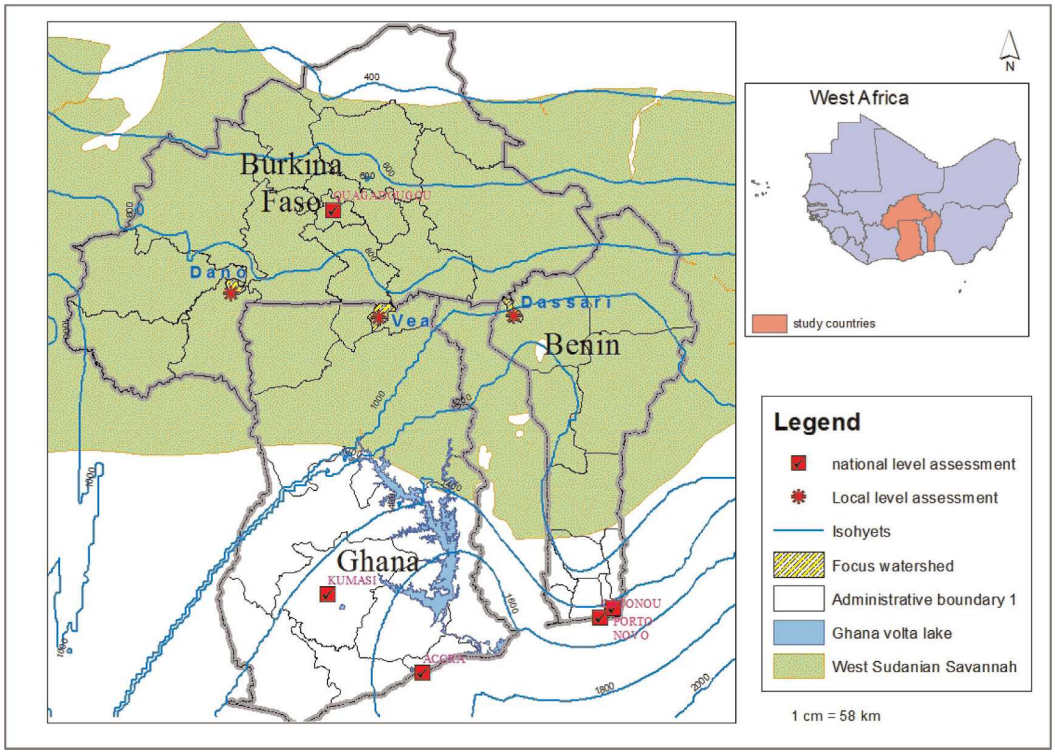

Figure 1: WASCAL study area (Asare-Kyei, 2017)

and cotton is also grown in Dano and Dassari. This is due to the support of cotton cultivation by the Beninese and Burkinabe authorities. Nevertheless, cotton cultivation often creates additional risks for the farmers as fertilizers are generally loaned and farmers may have problems to repay their debts in case of a poor harvest (Pardoe, 2016). In contrast to the watersheds of Dassari (Benin) and Dano (Burkina Faso), the Vea watershed in Ghana is located in proximity to the regional capital of Bolgatanga and is more urbanized. As such, the population there benefits from a broader range of services and opportunities such as a well developed road network, schools, market access, hospital and electricity. (Pardoe, 2016; Asare-Kyei, 2017) The population density with 104 persons/km2 in Vea is higher than in the other watersheds. For comparison, the population density is 56 persons/km2 and 59 persons/km2 in Dano (Asare-Kyei, 2017). There are many similarities between the villages such as scattered dwellings in the form of compounds, mainly made of mud/adobe whereas brick is becoming more common (Pardoe, 2016). In terms of disaster risk management all three case studies lack national institutional support and communities largely rely on themselves (Pardoe, 2016).

The handbook for practitioners that has been developed in the context of the **West Af rica Science Service Centre for Climate Change and Adapted Land Use (WASCAL)** consists of two different parts: PART I which contains the practical guidelines for assessing vulnerability and risk for climate-related hazards and PART II which has been conceptualized as a scientific background document for PART I. PART II is thus not a standalone document but should be read in conjunction with PART I. The handbook as a whole should be seen as a complement to numerous other guidelines and handbooks available, which provide highly valuable additional advice and examples of best practices for analyzing vulnerability and risk to natural hazards.

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Some relevant examples are: Risk Assessment Handbook (Rovins et al., 2015), The Vulnerability Sourcebook: Concept and guidelines for standardized vulnerability assessments (Fritzsche et al., 2014), or Tools for mainstreaming disaster risk reduction - guidance notes for development organizations (Benson, Twigg and Rossetto, 2007).

Understanding the need and usage of the guidelines

Why are vulnerability and risk assessments important

The Disaster risk management cycle

According to IPCC (2012), **disaster risk management** is defined as the "processes for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, and sustainable development." By contrast to **reactive risk management** that focuses on emergency response activities such as providing food, water, medical attention and shelter directly after a crisis has happened, **proactive risk management** aims to manage disaster risks focusing on identifying potential hazards, assessing vulnerabilities and preparing exposed communities for potential disasters with the aim to reduce potential impacts (WHO, 2014).

In general, the corresponding activities can be grouped into four **disaster risk management cycle** phases: **response, recovery, mitigation and preparedness**. The response phase follows the the immediate aftermath of the disaster when the hazard has become an event. During this phase assistance has to be provided to maintain life, improve health and support the morale of the affected population. In the subsequent recovery phase, the community returns to normal or ideally, the system is rebuild in a better way than it was. Response activities include returning vital life-support systems to minimum operating standards, health and safety education, reconstruction, counseling programs, and economic impact studies (GDRC, 2017). The activities within the mitigation phase are targeted towards the reduction or elimination of the probability of a hazard to occur or to minimize/eliminate its impacts. Mitigation measures include building codes, vulnerability analyses updates, zoning and land use management, building use regulations and safety codes, preventive health care, and public education. Within the preparedness phase a satisfactory level of readiness shall be achieved so that adequate response activities can be carried out in the case of an emergency. Preparedness activities include preparedness plans, emergency exercises/training, warning systems, emergency communications systems, evacuation plans and training; resource inventories, emergency personnel/contact lists, mutual aid agreements, and public information/education.

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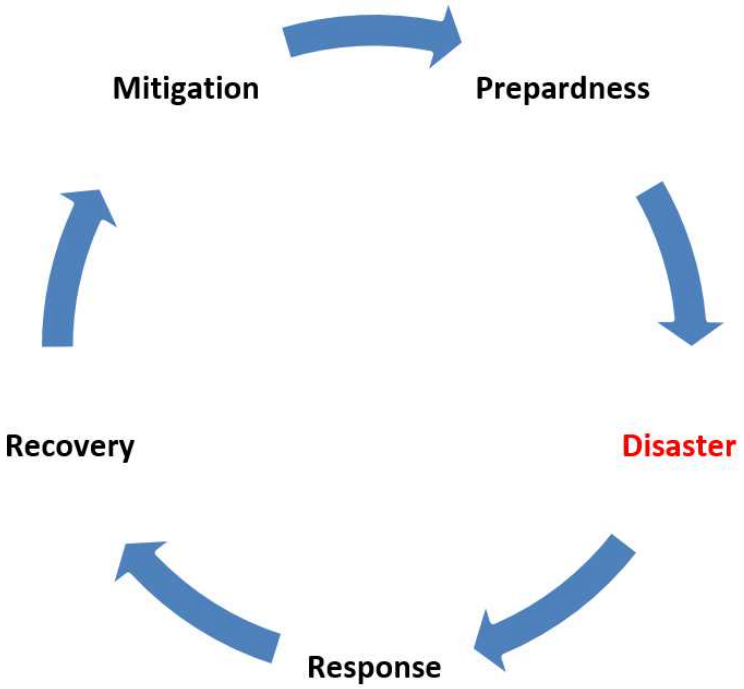

Figure 2: The Disaster Risk Management Cycle (according to information of (GDRC, 2017)

Context: The West Sudanian Savannah and climate-related hazards

The West Sudanian Savannah stretches from Senegal in the west to Nigeria in the east and is characterized by a uni-modal climate with a single rainy season that traditionally lasts from April to October while the rest of the year is dry. The rainy season normally starts with light rains in April, intensifies over June and July and finally peaks in August (Pardoe, 2016; Boansi, Tambo and Müller, 2017) . Floods and droughts in the region tend to be of low intensity but high frequency events.Despite of their relatively low intensity, these events have the potential to cause considerable damage to crops and livelihoods due to the high dependence of rural communities on rainfed-agriculture as their main source of income and the endemic regional poverty (Roncoli, Ingram and Kirshen, 2001; West, Roncoli and Ouattara, 2008; Pardoe, 2016). Moreover, high intensity flooding in the region occurs particularly along major rivers such as the Pendjari, Volta, Oti and the Niger river (Dziwornu and Kugbey, 2015; Kossi et al., 2016; Pardoe, 2016) and those events cause major damages. In September 2010, for example, 55 out of 77 Beninese municipalities were flooded by the Niger river. By this flood event alone 680 000 people were affected, 55 homes were destroyed and 800 cases of cholera were registered (Esty et al., 2005).

According to scientific observations, the total amount of annual precipitation has been relatively stable over the recent years. However, local perceptions as well as studies on regional climate patterns, such as conducted by Ibrahim et al. 2014 and Salack et al. 2014 suggest that floods and droughts in terms of increasing intra-seasonal variations become more frequent (Pardoe, 2016). According to their study results

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prolonged dry spells, the number of rainy days deceased, and intense rainfall events became more frequent (Ibrahim et al., 2014; Salack et al., 2015; Pardoe, 2016). Similarly, perceptions from farmers also reveal that 'false starts' of the rainy season i.e. dry spells shortly after the onset of the rainy season are on the rise so that the early rains are increasingly disregarded as a sign for the start of the growing season. Instead, households often wait with their sowing activities until the rains have 'set in' properly (Ibrahim et al., 2014; Salack et al., 2015; Pardoe, 2016).

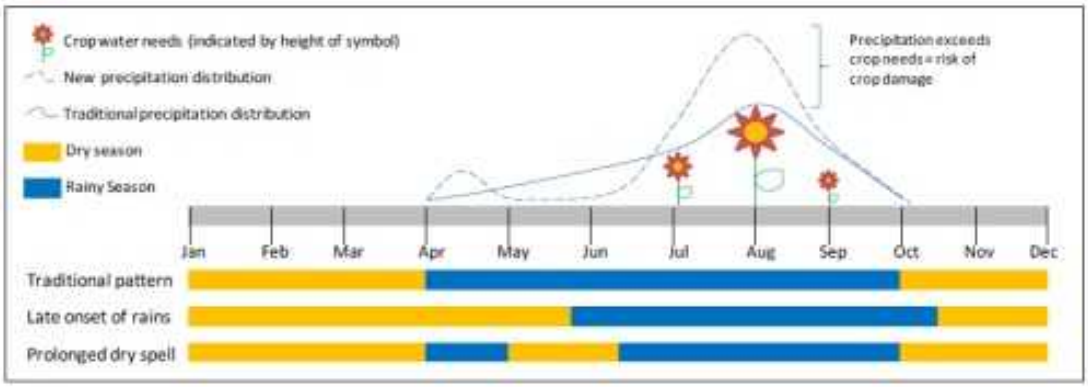

Figure 3: Traditional/ Normal seasonal precipitation pattern and current trends under climate change conditions compared to crop needs (Ibrahim et al., 2014; Salack et al., 2015; Pardoe, 2016)

Nonetheless, a similar climatic hazard exposure within a region does not necessarily lead to the same intensity of impacts within the affected communities. Instead, the actual impacts decisively depend on the vulnerabilities in terms of exposure, susceptibilities as well as coping and adaptation strategies that prevail within different communities. They are shaped by a multitude of biophysical and socio-economic factors such as the degree of soil erosion, soil quality and fertility, low input farming systems, decreased fallow periods, deforestation, low levels of literacy and limited access to improved water and sanitation (USAID, 2011; Asare-Kyei, Kloos and Renaud, 2015; Pardoe, 2016). In addition, it should be kept in mind that the vulnerabilities vary among individual households and individuals within a community.

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Step 1: Understanding and planning the vulnerability and risk assessment

Definitions and components of risk

Adaptive capacity

"The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014a: 118).

Coping capacity

"The ability of people, organizations, and systems, using available skills, resources, and opportunities, to address, manage, and overcome adverse conditions" (IPCC, 2012a: 558).

Exposure

"The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC, 2014a: 123).

Hazard

"The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts" (IPCC, 2014a: 124).

Multi-Hazard

"(1) two or more extreme events occurring simultaneously or successively, (2) combinations of extreme events with underlying conditions that amplify the impact of the events, or (3) combinations of events that are not themselves extremes but lead to an extreme event or impact when combined. The contributing events can be of similar (clustered multiple events) or different type(s)" (IPCC, 2012b: 118).

Risk

"The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. In this report, the term risk is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure" (IPCC, 2014a: 127).

Susceptibility

"physical predisposition of human beings, infrastructure, and environment to be affected by a dangerous phenomenon due to lack of resistance and predisposition of society and ecosystems to suffer harm as a consequence of intrinsic and context conditions making it plausible that such systems once impacted will collapse or experience major harm and damage due to the influence of a hazard event" (Cardona et al., 2012: 72).

Vulnerability

"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2014a: 128).

Vulnerability: Schools of thought

The concept of vulnerability was introduced in the 1970s and in general it stresses the **importance of social factors and societal structures in the formation of risk**. Today it is widely accepted that the consequences of natural hazards do not depend on the magnitude of the physical event alone and that vulnerability plays a decisive role in disaster risk reduction and climate change adaptation (Birkmann, 2013b). Even though, the concept is still actively discussed in literature (Kloos et al., 2015) and defined and framed differently by various scientific communities and disciplines. In this regard, at least four different schools of thoughts can be distinguished: **political economy, social-ecology, disaster risk assessment from a holistic view and climate change systems science** (Birkmann, 2013b).

The perspective of **political economy** is associated with Sen's (1981) entitlement approach and focuses on socioeconomic and political structures. According to this view, the differences in loss and damage of natural hazards can be explained by the social, economic, cultural and political contexts that people are living in. The pressure and release (PAR) model (Blaikie et al., 1994, 1996; Wisner et al., 2004) summarizes the structural perspective. It explains how political and economic root causes translate into dynamic pressures (such as rapid urbanization, deforestation and lack of local markets) and unsafe conditions (such as unprotected buildings, dangerous locations and lack of local relief institutions) that determine the final hazard outcome (Hufschmidt, 2011).

The approaches to **disaster risk assessments from a holistic view** go back to the work of Cardona (Cardona, 1999, 2001) and were then further developed by Bogardi and Birkmann 2004 and others whereas the ideas were, for example, conceptualized within the BBC and MOVE frameworks . Their work is linked to holistic and integrative perspectives on vulnerability while the concept has been extended towards social, economic, cultural, environmental and institutional features (Birkmann, 2013b). Similarly to the climate change adaptation community, the disaster risk management community aims to understand and reduce the risk that has been created by the interaction of the human with the physical system while increasingly placing emphasis on sustainable social and economic development. Even though, the disaster risk

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management community evolved under the premise of a stationary climate and tended to encourage bottom-up and grass-roots approaches (IPCC, 2012b)

The introduction of **social-ecological thinking** and the operationalization of the concept of resilience for disaster risk management and climate change adaptation occurred in the early 2000s (Birkmann, 2013b). Social-ecologists emphasize the interconnectedness of the social and the natural systems and underline the importance of the capacity of systems for self-organization, learning and transformation in order to better deal with shocks and surprises (Hufschmidt, 2011; Birkmann, 2013b). In order to address the vulnerability of a system, social-ecologists promote different combinations of adaptation activities instead of specializing on single measures to overcome deficiencies and pitfalls of unilateral strategies. (Hufschmidt, 2011). The framework of Turner et al. 2003 is one of the most prominent frameworks of this school of thought.

The **climate change adaptation community** evolved within the frame of the IPCC Working Group II while building on the work of Füssel & Klein, 2006 The changing patterns of risk that evolve due to both climatic change and socio-economic development as well as principles for effective risk management strategies are at the core of climate change adaptation research. By doing so, the dynamic nature of vulnerability is emphasized and climate-related risk management is viewed within the broader context of sustainable development. Given the high uncertainty that is related to future developments and risks, the need for low regret measures and iterative risk management strategies is underlined. Iterative risk management shall ultimately lead to climate resilient pathways. Moreover, the needs, options, opportunities, constrains and limits of adaptation are of central concern for the climate change adaptation community (IPCC, 2014b).

Core concepts of vulnerability that reappear in various definitions include **susceptibility or sensitivity** as well as **coping and adaptive capacity** (Birkmann, 2013b).

Step 1.1 What is the purpose of the assessment?

Adaptation Strategies

Adaptation can be defined as permanent adjustment to climatic stressors while aiming to reduce risk and vulnerability (Tompkins et al., 2010; Pardoe, 2016). By doing so, adaptation attempts to anticipate future impacts on human society and ecosystems (IPCC, 2012b). Adaptation options cover a wide spectrum of strategies while including structural/ physical, social and institutional measures (Noble et al., 2014).from different academic disciplines. (IPCC, 2012b).

The main adaptation actions that have been undertaken in the WASCAL case study areas include **changes in view of the planting time, relocations of both farms and houses, the usage of improved seeds, compost and the exploitation of additional sources of income** (Pardoe, 2016; Pardoe, Kloos and Assogba, 2016). Despite of their potential to adapt to a changing climate, all of these strategies are associated with

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specific limitations and barriers and their long-term sustainability is particularly limited due to the lack of holistic and coordinated approaches. With regard to the adjustment of the planting time, both **planting early and planting late** are practiced. However, both practices remain a gamble as the seasonal variability is highly uncertain.. By planting early, farmers aim to benefit from the rains as early as possible. Even though, in case of a break of the rains for more than two weeks at the beginning of rainy season, crops have to be re-sown. In order to avoid the risk caused by such dry spells, other farmers plant late and wait until the rains have set in properly. As a consequence of planting late, the growing season might be too short for particular crops so that this adaptation strategies will result in reduced harvests. Another option are mixed planting strategies where sowing activities are split into two parts and some crops are planted early and others are planted late. By doing so, farmers assure that they do not need to replant the entire crop area. However, this strategy is also suboptimal as weather conditions will favor one part of the harvest and not the other (Pardoe, 2016; Pardoe, Kloos and Assogba, 2016). Concerning the **relocation of farms and houses**, available land is likely to be limited. By contrast, the benefit of **improved short cycle seeds** is well accepted by both experts and farmers. However, they are generally obtained from organizations such as the Agricultural Departments and extension services and thus the access to the seeds may constitute a problem. In addition, they are not necessarily available for free and might require the farmers to the take out a loan. Difference in quality and storage life might pose barriers as well. **Compost** making and its use as organic fertilizer is another strategy that is promoted by NGOs and international development organizations. Compost has the potential to improve soil fertility and water holding capacity and thus farm productivity as well as drought resilience. One of the main challenges with regard to this adaptation strategy relates to the access to water during dry season which is required for the composting process. The availability of animal dung can be another limiting factor. The exploitation of additional sources of income constitutes another promising option. For example, the cultivation and use of trees such as baobab, shea, néré, cashew and mango can generate an additional source of income. Even though, the organization of the value chains is weak and the marketing of the products is often difficult. The uptake of a secondary permanent non-climate dependent occupation to support the income from farming in anticipation of future drought and flood losses is another option jn this context, shop keeping, tailoring and the sale of local beer are the most common additional sources of income. These activities might be impacted by floods and droughts as well in case that they rely on farmers as costumers. On the other hand, occupations such as masonry and carpentry services might even benefit from hazardous events (Pardoe, 2016; Pardoe, Kloos and Assogba, 2016).

Disaster Risk Reduction Measures

According to the IPCC 2012, **disaster risk reduction** denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk, reducing existing exposure, hazard, or vulnerability, and improving resilience. This includes lessening the vulnerability of people, livelihoods, and assets and ensuring the appropriate sustainable management of land, water, and

other components of the environment." Effective disaster risk reduction acknowledges the strong interrelations between disaster risk, disaster risk management, development and development planning. Moreover, disaster risk reduction shares many goals, concepts and processes with climate change adaptation even though these fields emerge from two different academic communities. The management of both current and future risks will improve by exploiting potential synergies. In general, the disaster risk community can learn from the adaptation community on how to effectively address future conditions while the adaptation community can learn on how to address current impact (IPCC, 2012b).

Indicators

Indicators are key tools to measure vulnerability as well as the progress towards disaster risk and vulnerability reduction. Vulnerability indicators can be defined as variables which are operational representations of a characteristic "or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event linked with a hazard of natural origin (Birkmann, 2006)." Their main functions comprise the setting of priorities, to establish a background for action, to raise awareness, to allow for trend analysis as well as empowerment (Birkmann, 2006; Cardona et al., 2012). The ideal indicator development process builds on nine different phases:

• Definition or selection of relevant **goals**

• Carry out a **scoping process**: identify the target group and the associated purpose, define temporal and spatial bounds

• Identification of an appropriate **conceptual framework** to structure the potential themes

• Definition of **selection criteria** of the potential indicators: link general criteria such as "relevant", "analytically and statistically sound", "reproducible" and "appropriate in scope" to the specific theme, function and goal

• Identification of a **set of potential indicators** and evaluation of the indicators with reference to the criteria developed at an earlier stage

• **Collection of data**

• **Preparation of a report**

• **Assessment of the indicator performance** (Maclaren, 1996; Birkmann, 2006, 2013a)

Step 1.3 Which systems will be assessed?

Socio-ecological systems

Socio-ecological system (SES) thinking is a relatively new discipline and addresses the interdependence between human society and the ecosystem while drawing on systems ecology and complexity theory (Folke et al., 2010; Cumming, 2011). An SES

can be defined as an "integrated system of ecosystems and human society with reciprocal feedback and interdependence (Folke et al., 2010) ". It can be characterized in terms of its complex behaviors that include feedbacks, the existence of thresholds, the potential for **alternative stable states and self-organization** (Norberg & Cumming, 2008). Change rather than equilibrium is the normal state of a SES (Holling, 1973) while internal feedback processes and control variables keep the system within a specific stability domain or stable state. These feedback processes typically act across multiple scales and add to the capacity of the system to absorb disturbances and to self-organize into a particular structure and function. The existence of multiple stable states or stability domains that are each defined by a set of controlling variables with specific threshold levels is characteristic for SESs (Folke et al., 2010; Kloos et al., 2015). The different stability domains form the so called stability landscape. Gradual changes or sudden perturbations can move the system towards specific thresholds and cause a change in critical feedback processes so that the system shifts from one state of the stability landscape to another (Cumming, 2011; Kloos et al., 2015). The system then self-organizes along a different trajectory within the new stability domain (Folke et al., 2010). These systemic shifts are hardly predictable (Cumming, 2011). Oftentimes, they are socially undesirable and have negative impacts on ecosystem services and human wellbeing (Kloos et al., 2015). SESs can be close to or far away from thresholds, they can be easy or hard to change and the range of dynamics that can be accommodated can be large or small (Walker et al., 2004). Different **frameworks** have been developed within the context of SES theory such as the SES Sustainability Framework (Ostrom, 2007, 2009), the Ecosystem Stewardship Frawework (Chapin III, Kofinas and Folke, 2009; Chapin et al., 2010) or the Management and Transition Framework (Pahl-Wostl, 2009; Pahl-Wostl et al., 2010). All of these frameworks allow for a structured reasoning about complex problems in socio-ecological systems but differ significantly in view of contextual and structural criteria such as the ecological and social subsystems and their interrelations. In this respect, Binder et al. 2013 analyzed 10 established frameworks by comparing on whether the social and ecological systems are conceptualized as uni- or bidirectional, on whether they treat the social and ecological systems in equal depth, and on whether they are action- or analysis-oriented (Binder et al., 2013).

Step 1.4: Which sectors need to be involved?

Sectors

According to a categorization scheme of the IPCC 2014, the main sectors that will be affected by climate change risks comprise

- freshwater resources
- terrestrial and freshwater ecosystems
- coastal systems and low-lying areas
- marine systems

- food security and food production systems
- urban areas
- rural areas
- key economic sectors and services
- human health, human security
- livelihoods and poverty

Freshwater-related risks include primarily water scarcity, a reduced water quality and the occurrence of floods. These risks can be mitigated by adapted water management techniques. The main risks related to terrestrial and freshwater ecosystems comprise habitat modification, overexploitation, pollution, invasive species and the risk of extinction. These risks can be mitigated by management actions, such as maintenance of genetic diversity, assisted species migration and dispersal as well as manipulation of disturbance regimes. Coastal systems and low-lying areas are predominantly at risk of submergence, coastal flooding and coastal erosion. The relative costs of coastal adaptation to protect exposed population and assets could reach several points of GDP in some countries and small island states. The risks relating to marine systems challenge the sustained provision of fisheries productivity and other ecosystem services so that marine management regimes are complicated. Food security and food production systems are posed at risk by severe yield impacts and redistribution of marine fisheries. Consequently, reduced supplies, income and employment can have potential effects on food access, utilization and price stability. Many risks are concentrated in urban areas that are caused by heat stress, extreme precipitation, inland and coastal flooding, landslides, air pollution, drought or water scarcity. The risks are further amplified by the lack of essential infrastructure and services, poor-quality housing and living in exposed areas. Reducing basic service deficits, improving housing and building resilient infrastructure systems can thus substantially reduce vulnerability. By contrast, rural areas are primarily at risk of a lack of water availability and supply, food insecurity, a lack of income and a shift in production areas whereas female-headed households, those with limited access to land, modern agricultural inputs, infrastructure and education are most affected. Adaptation can occur through policies taking account of rural decision-making contexts. Two of the key economic sectors and services that are most at risk are the energy and the insurance sector. However, for most economic sectors, non-climate related drivers such as changes in population will play a prominent role. Human-health related risks include an increased likelihood of injury, disease, under-nutrition, death. The most effective vulnerability reduction measures are programs to improve basic public health measures, secure essential health care and alleviate poverty. Risks related to human security mainly concern changes in migration patterns whereas the risks related to livelihoods and poverty comprise exacerbated poverty, new poverty pockets and food insecurity. Livelihood resilience may be enhanced by insurance programs, social protection measures and disaster risk management (IPCC, 2014b).

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Step 1.9: Who should be consulted during the assessment? (Main stakeholders)

Table1: Stakeholders that were consulted during the WASCAL workshops

GHANA	
National Disaster Management Organization (NADMO)	http://www.nadmo.gov.gh/
Community Resilience Through Early Warning (CREW) project	https://crewghana.wordpress.com/
Ghana Statistical Service (GSS)	http://www.statsghana.gov.gh/
Ministry of Food and Agriculture (MoFA)	http://mofa.gov.gh/site/
Environmental Protection Agency (EPA)	http://www.epa.gov.gh/epa/
Water Research Institute (WRI)	https://www.csir-water.com/
Department of Geography and Resource Development, University of Ghana, Legon	http://www.ug.edu.gh/geography/
Mercy Corps	https://www.mercycorps.org/about-us
BENIN	
Agence Nationale de Protection Civile (ANPC)	http://anpcbenin.org/index.php/actualite
Ministere de la Decentralisation, de la Governance locale et de l'amenagement du Territoire (MDGLAAT)	http://www.decentralisation-benin.org/
Ministère de l'Environnement, de l'Habitat et de l'Urbanisme (MEHU)	http://gouv.bj/
BURKINA FASO	
WASCAL Competence Centre	http://www.wascal.org/about-wascal/our-team/competence-center/
Comité National de Secours d'Urgence et de Réhabilitation (CONASUR)	http://www.conasur.bf/
Institut de l'Environnement et Recherches Agricoles (INERA)	http://www.inera.bf/
Direction Générale de la Protection Civile (DPC)	
Ministère de l'Agriculture de l'Hydraulique et des Recherches Halieutiques (MAHPH)	www.agriculture.gov.bf/
Centre d'Etudes, de Documentation et de Recherche Economiques et Sociales (CEDRES), Université de Ouagadougou	http://www.cedres.bf/
Service météorologique	http://www.meteoburkina.bf/
The Challenge Programme on Water and Food (CPWF-Volta)	https://waterandfood.org/
Institut International d'Ingénierie de l'Eau et de l'Environnement (2IE)	http://www.2ie-edu.org/
United Nations Development Programme (UNDP)	http://www.undp.org/
Croix-Rouge Burkinabé	http://www.ifrc.org/fr/introduction/ou-intervenons-nous/africa/croix-rouge-burkinabe/

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Step 2: Conducting the hazard assessment

Multiple versus single-hazard assessments

Socio-ecological systems are rarely threatened by a single hazard alone. Most often they are exposed to multiple hazards that overlap spatially and/or temporally (Kappes et al., 2012).Within a multi-hazard environment, possible interactions and interrelations have to be taken into consideration. These interactions include, for example, the occurrence of **cascading effects** that emerge when one hazard triggers another or the occurrence of **compound hazards** that are caused by the interaction of several elements such as wind, hail and lightening. Moreover, hazards can be **mutually exclusive** or they can occu**r independently** from one another or **in succession** (Liu, Siu and Mitchell, 2016; Pardoe, 2016). The analysis of hazard relations is still an active and relatively new area of research and no common terminology is existent so far. Different conceptual approaches for their analysis have been developed by different authors (Kappes et al., 2012). In this regard, **matrix** (e.g. De Pippo et al., 2008) or **event trees** (e.g. Garcia-Aristizabal, Marzocchi, & Di Ruocco, 2013) are commonly used methods (Liu, Siu and Mitchell, 2016). By contrast to descriptive matrix, event trees aim to assign possibilities to possible scenarios following an initial event. They are however highly data demanding, especially when applied on a small scale (Kappes, Keiler and Glade, 2010; Kappes et al., 2012).

Step 2.1 Defining the natural hazard under consideration?

Classification of hazard types

Hazards can be classified into several broad categories. Depending on their genesis, the International Disaster Database of the Centre for Research on the Epidemiology of Disasters distinguishes geophysical/geological, meteorological, hydrological, climatological and biological hazards (Centre for Research of the Epidemiology of Disasters, 2017). According to this classification scheme they can be defined as follows (Centre for Research of the Epidemiology of Disasters, 2017):

• Geophysical/geological hazards: originate from solid earth (mass movements, earthquakes, volcanic activities)

• Meteorological hazards: caused by short-lived, micro- to meso-scale extreme weather and atmospheric conditions that last from minutes to days (extreme temperatures, fog, storms)

• Hydrological hazards: caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater (floods, landslides, wave actions)

• Climatological hazards: caused by long-lived, meso- to macro-scale atmospheric processes ranging from intra-seasonal to multi-decadal climate variability (droughts, glacial lake outbursts, wildfires)

• Biological hazards: caused by the exposure to living organisms and their toxic substances or vector-borne diseases that they may carry (epidemics, insect infestations, animal accidents)

• Extraterrestrial hazards: caused by asteroids, meteoroids

Background literature with regard to climatic change in West Africa

Alhassane, A., Salack, S., Ly, M., Lona, I., Traore, S.B., Sarr, B. (2013). Evolution des risques agroclimatiques associés aux tendances récentes du régime pluviométrique en Afrique de l'Ouest soudano-sahélienne. Sécheresse 24: 282-93.

Ibrahim, B., Karambiri, H., Polcher, J., Yacouba, H., Ribstein, P. (2014). Changes in rainfall regime over Burkina Faso under the climate change conditions simulated by 5 regional climate models. Climate Dynamics 42: 1363-138.

Kabore/Bontogho T.-N. P. E., Boubacar, I., Boubacar, B., Helmschrot, J. (2015). Intra-Seasonal Variability of Climate Change in Central Burkina Faso. International Journal of Current Engineering and Technology, 5, 3: 1955-1965.

Laux, P., Kunstmann, H., Bárdossy, A. (2008). Predicting the regional onset of the rainy season in West Africa. International Journal of Climatology 28: 329-342.

Neumann, R., Jung, G., Laux, P., 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: 7-30.

Sarr, B. (2012). Present and future climate change in the semi-arid region of West Africa: a crucial input for practical adaptation in agriculture. Atmospheric Science Letters 13: 108-112.

Sylla, M., Giorgi, F., Pal, J., Gibba, P., Kebe, I., 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 28(16): 6475- 6488.

Sylla, M.B., Nikiema, P.M., Gibba P., Kebe, I., Browne Klutse, N.A. (2016). Climate Change over West Africa: Recent Trends and Future Projections. In: Yaro, J.A., Hesselberg, J. (eds.). Adaptation to Climate Change and Variability in Rural West Africa: 25-40

van de Giesen, N., Liebe, J., Jung, G. (2010). Adapting to climate change in the Volta Basin, West Africa. Current Science 98(8): 1033-1037.

a. Drought

Droughts are periods of abnormally dry weather conditions that are long enough to cause serious hydrological imbalances. Drought is a relative term and refers to particular precipitation related activities (IPCC, 2013). In that respect, four different drought categories are typically distinguished: meteorological, agricultural,

hydrological and socio-economic droughts. Prolonged dry conditions caused by precipitation deficits and high temperatures and increased evaporation are initially designated as **meteorological droughts**. They may further translate into soil moisture deficits with impacts on crop and biomass production as well as ecosystem functioning in general. These conditions are termed **agricultural droughts**. **Hydrological droughts** can occur as a result of storage changes in surface or subsurface water supplies. Imbalances in water supply and water demand with impacts on the economy and society are finally referred to as **socioeconomic droughts** (IPCC, 2013; TT-DEWCE-WMO, 2016).

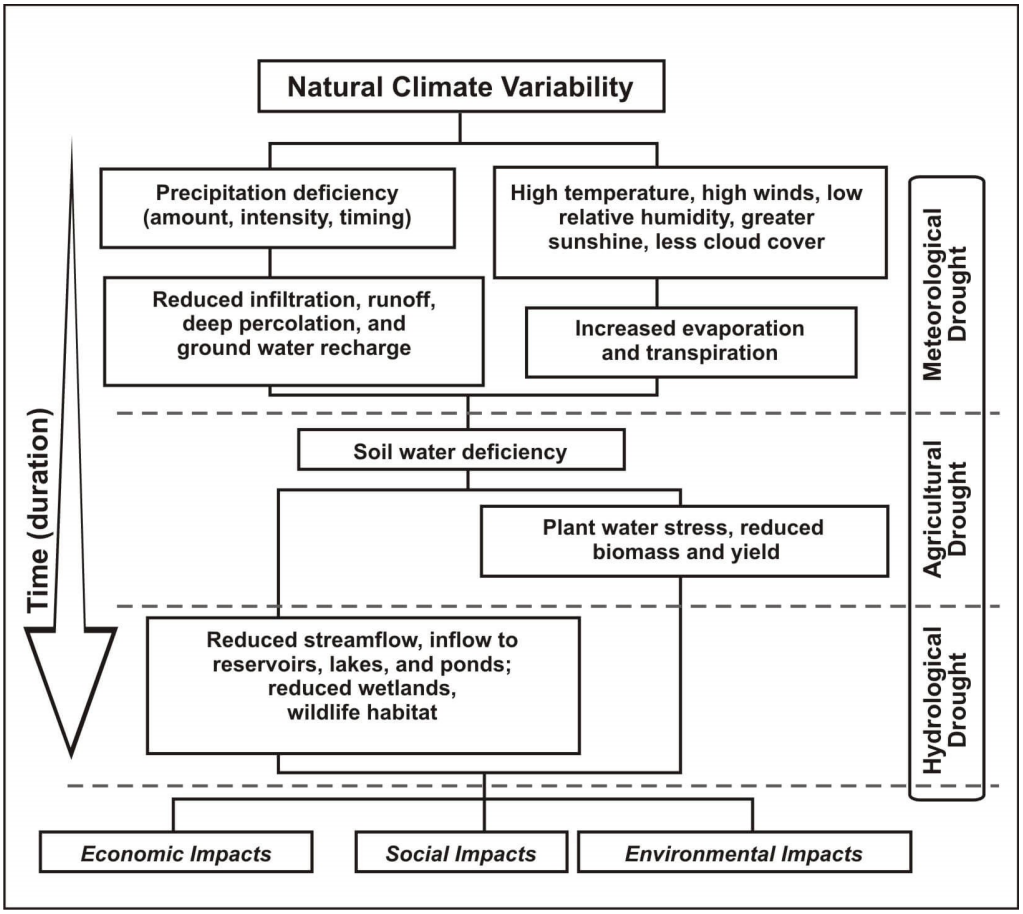

Figure 4: Types of Drought (National Drought Monitoring Center, 2017)

b. Dry spell

According to the WMO Meteoterm terminology, a dry spell is defined as "period of abnormally dry weather [whereas the] use of the term should be confined to conditions less severe than those of a drought (WMO, 2017)". In terms of its duration a dry spell can be further characterized as "A period of unusually dry conditions of at least five consecutive days with daily precipitation less than 1mm (TT-DEWCE-WMO, 2016)"whereas the term should not be used for usually dry periods, such as during dry seasons (TT-DEWCE-WMO, 2016).

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Step 2.2 Assessing hazards

Step 2.2 – Option 1: Hazard event inventory

1. Collect data on hazard occurrence and impacts from local, regional and national disaster risk management agencies and other databases

Disaster risk management agencies in the WASCAL countries

Table 2: Disaster Risk Management Agencies of the WASCAL countries

Country	Disaster Risk Management Agency	Weblink
Senegal	Direction de la Protection Civile, Ministère de l'Intérieur (DPC)	http://www.gouv.sn/
Gambia	National Disaster Management Agency (NDMA)	http://www.ndma.gm/
Mali	Direction Générale de la Protection Civile (DGPC)	http://www.securite.gouv.ml/
Niger	Dispositif National de Prévention et de Gestion des Catastrophes et Crises Alimentaires (DNPGCCA)	http://www.dnpgcca.ne/
Burkina Faso	Conseil National de Secours d'Urgence et de Réhabilitation, Ministère de l'Action Sociale et de la Solidarité National (CONASUR)	http://www.conasur.bf/
Cote d'Ivoire	Office National de la Protection Civile (ONPC)	http://www.onpc-ci.org/
Ghana	National Disaster Mangement Organization (NADMO)	http://www.nadmo.gov.gh/
Togo	Agence Nationale de la Protection Civile (ANCP)	http://securite.gouv.tg/fr
Benin	Agence Nationale de la Protection Civile (ANCP)	http://anpcbenin.org/
Nigeria	National Emergency Management Agency (NEMA)	http://www.nema.gov.ng/

Relevant data sources

Table 3: Relevant Data Sources

What	Hazard inventory data mapping	Remote sensing data analysis	Participatory hazard mapping
Who	Disaster management specialist	RS / GIS technician	Community stakeholders
Relevant data Data sources	• International Disaster Database EM-DAT •MunichRedatabasefornatural catastrophes (NatCatSERVICE) • Dartmouth Flood Observatory (DFO) • Global Disaster Alert and Coordination System GDACS • Global Risk Data Platform PREVIEW (2014) of the United Nations Environment Programme (UNEP) • UNITAR (2014) hosts maps and analytical reports produced by the UN Operational Satellite Applications Programme (UNOSAT)	• passive optical systems • active radar systems • active light detection and ranging systems • A comprehensive database on (free of charge) earth observation and further GIS data is provided by the UN-SPIDER Knowledge Portal on Space-based information for Disaster management and Emergency response (UN-SPIDER, 2016):	

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GPS mapping and coordinate systems

GPS is a satellite-based navigation system that provides a means of obtaining coordinate locations on mobile receiving devices. Those can be handheld devices with the sole purpose of obtaining and recording spatial locations or they can be embedded into broader purpose devices such as mobile phones, automotive and marine navigation systems, mobile mapping systems as well as PCs and Laptops (Li et al. 2011). An up-to-date list of open source GPS software for different operating systems and devices can be found under the following link: *http://www.maps-gps-info.com/fqpfw.html.*

Locations of geographic features are represented based on coordinate systems. In this regard, geographic coordinate systems (GCS) can be distinguished from projected coordinate systems (PCS). In contrast to PCSs, GCSs are based on a three-dimensional (3D) spherical surface whereas individual locations are represented by longitude and latitude values as measured from the earth's centre in angular units. There are several hundred geographic coordinate systems but WGS-84 is the most commonly used standard spheroidal reference ellipsoid. By contrast, PCS are based on the map projection of a spheroid by a mathematical transformation and defined on a two-dimensional (2D) surface. A PCS has constant lengths, angles and areas across the two dimensions and measured in linear units. There are several thousand PCS available but the Universal Transverse Mercator (UTM) system is one of the most commonly used PCS worldwide (ESRI, 2017). Further information on coordinate systems, GCSc, PCSs as well as specific GCSs and PCSs can be found in the ArcGIS Resource Center under the following weblink: *http://help.arcgis.com/en/sdk/10.0/arcobjects_net/conceptualhelp/index.html#//0001000002mq000000.*

Table 4: Licensed and Open Source Database Management Software

Software	Open Source/ Licensed	Weblink
Libre Office Base	Open Source	*https://www.libreoffice.org*
Open Office Base	Open Source	*https://www.openoffice.org//*
Google Fusion Tables	Open Source	*http://google.com/fusiontables*
MySQL	Open Source	*http://www.mysql.com*
Postgre SQL	Open Source	*http://www.postgresql.org*
SQLite	Open Source	*https://www.sqlite.org/*
MongoDB	Open Source	*https://www.mongodb.com/*
MariaDB	Open Source	*https://mariadb.org/*
Firebird	Open Source	*http://www.firebirdsql.org/en/start/*
CUBRID	Open Source	*http://www.cubrid.org/*
Microsoft Access	Licensed	*https://products.office.com/en-us/access*
Oracle	Licensed	*http://www.oracle.com*
IBM DB2	Licensed	*http://www.ibm.com/db2/*

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Step 2.2 – Option 2: Participatory hazard mapping

Participatory Geographical Information System (PGIS)

PGIS is an emergent practice that combines participatory planning approaches with a range of geo-spatial information management tools (Rambaldi et al., 2006). The practice came into being in the 90s and builds on the fruitful collaboration between GIS practitioners and development studies scholars (Dunn, 2007). A good PGIS is demand-driven, user-friendly, flexible and embedded into long-lasting spatial decision-making processes (Rambaldi et al., 2006). It aims to contribute to good governance by improving dialogue, transparency as well as legitimacy. Moreover, PGIS promotes empowerment by the appreciation of local and indigenous knowledge, by exposing local stakeholders to geospatial analysis and by involving community members in decision-making and actions (Mccall and Minang, 2005). Further information on principles, guidelines, projects, ethics, PGIS tools and discussion forums in various languages can be found at: *http://pgis.cta.int/en/about-pgis/ethics.html.*

Step 2.2 – Option 3: Remote sensing based hazard mapping

Different types of Earth-Observation data for hazard assessment

Different sensors types (active vs. passive) provide different spectral, geometric and radiometric Earth Observation data. Depending on the spatial detail that is needed and the hazard type to be analyzed, a selection can be done. With regard to the hazard type, it should be noted that flood events are often associated with a relatively high percentage of cloud coverage so that data from active sensors will be required whereas drought assessments generally involve the usage of longer time series.

Example: The goal is to monitor a flood within a city.

This goal specifies that the extent of a city is usually around 10x10 km, so a relatively small area of interest. This in turn means that it is of relevance that we identify in spatially highly accurate manner the extent of the flood. We recommend using very high resolution satellite data in the dimension of 40cm to 3 meters to capture the spatial detail – if clouds are no obstacle. In case clouds prohibit the use of passive, optical satellite data, active radar data are required.

Table 5: Example: EO data acquisition for flood monitoring within a city

Hazard type	Extent	Recommended Earth observation data
Flood	• Example: City	• If it is cloudy – radar data with high resolution (e.g. TerraSAR-X spotlight • If there are no cloud – optical satellite data (e.g. from WorldView) with a near nadir perspective • If there is no budget for data acquisition – data from Sentinel-1 (radar) or Sentinel-2 (optical) with lower resolutions

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Example: The goal is to assess drought hazard for a specific region

Due to the unavailability of longer time series with regard to high resolution images, remote sensing based drought assessments are generally conducted at a regional scale. With acquisitions being available since 1978, AVHRR data and derived indices from it with a spatial resolution of 4 km are a good option, MODIS products at a resolution of 250-1000m that are available since 2000 are a viable alternative

Table 6: EO data acquisition for a drought hazard assessment of a specific region

Hazard type	Extent	Recommended Earth observation data
Drought	• Example: Region	• Medium resolution data (AVHRR) as long time series needed

As there are many possible sensors we provide in the following table prominent examples for active as well as passive sensors with different spatial, spectral and temporal resolutions that can be used for drought and flood hazard assessment.

Table 7: Different types of EO data for hazard assessments

Data acquisition technique (Type of sensor)	Missions, Satellites (further specifictaion)	Spectral resolution	Spectral resolution	Available since	Repeat cycle	Accessibility	Licence	Appropriate for flood (+) and drought (-) detection
RADAR (Active)	Sentinel-1 (C-Band-SAR)		5m		12 days repeat cycle	Free of charge		+
	TerraSAR-X (x-Band-SAR)		3m		11 days	Not Free of charge		+
Optical (Passive)	Sentinel-2	Superspectral	10-60m		0 days	Free of charge		+
	MODIS	Superspectral	250-1000m		16 days	Free of charge		+,-
	WorldView-4	Multisprectral	0.31cm		Few days	Not Free of charge		+
	AVHRR							+

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Websites for data download

The selected Earth observation data sets can be ordered either from commercial providers of satellite data or from data hubs providing the data for free. For our example, the acquisition of optical satellite data from WorldView are for example possible at European Space Imaging.
The following list provides links to important websites for data download:

For drought hazard assessment long time periods of assessment are of relevance. We recommend using MODIS data for long-time monitoring for large areas. The data can be downloaded for free at:
https://modis.gsfc.nasa.gov/data/

For flood hazard assessment we recommend – as long as clouds are no obstacle – medium resolution optical satellite for mapping flood extents. Data e.g. from Landsat are available at the GLCF server:
http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp
or the USGS servers:
http://glovis.usgs.gov/
https://code-de.org/

At these homepages please follow the following steps for data download: Select the sensor, select the desired spatial extent, select the date or time span required, use the filter for finding images with specific details (e.g. maximum cloud coverage allowed).

In case, the highest detail is necessary, the acquisition of highest resolution optical satellite data from WorldView is possible at European Space Imaging:
http://www.euspaceimaging.com/satellite-imagery/georeferenced-products

Link to International Charter Space and Major Disasters:
https://disasterscharter.org/web/guest/activations/charter-activations --> acquisition and processing of data during huge events.

AVHRR data and derived indices available here:
https://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_ftp.php **-->** simple download, covers the whole globe.

Scientific overview on relevant studies

A large body of literature exists on the capabilities of Earth observation for assessment of natural hazards, exposed elements, the vulnerability of exposed elements and the resulting risks up to interventions strategies. Remote sensing holds capabilities for analyzing natural hazards such as droughts (e.g. Rhee, Im, & Carbone, 2010), floods (e.g. Martinis, Twele, & Voigt, 2011), earthquakes (e.g. Joyce, Belliss, Samsonov, McNeill, & Glassey, 2009), wildfires (e.g. Wooster et al., 2013), tsunamis

(e.g. Taubenböck et al., 2009), among many others. It also holds capabilities for deriving exposed elements such as the built environment (e.g. Geiß & Taubenböck, 2013) or population (e.g. Aubrecht, Özceylan, Steinnocher, & Freire, 2013), among others and assessing the related vulnerability of the exposed elements (e.g. Geiß et al., 2014).

Hazard assessment is carried out at various scales, and the methods for hazard assessment are determined by the type of hazard and by the availability of input data In the following we are focusing on flood and drought hazard assessment approaches as they are the most relevant in Western Africa. However, a comprehensive summary on flood and drought hazard assessment approaches cannot be provided and would be out of and the focus of this guideline.

The table below presents selected relevant studies on flood and drought hazard assessment using remote sensing and GIS techniques. In general the methods on flood detection and analysis refer to the direct classification of surface water by spectral information in optical satellite data or the low backscatter signal in radar data. The methods on drought analysis predominantly rely on indices assessing the vegetation (health) and thus allow for indirect monitoring of effects of drought events.

Table 8: Selected actual literature for methodological approaches on flood and drought hazard assessment using remote sensing and GIS techniques

Disaster type	Source	Document type	Content
Flood	Lawal, 2011	Flood hazard management applications	Review of applications of GIS and remote sensing technology in flood disaster monitoring and management.
Flood	Taubenböck et al., 2011	Remote Sensing of floods	Multi-scale analysis of capabilities of flood detection and modelling based on various Earth observation data sets
Flood	Martinis et al., 2011	Remote Sensing of floods	Classification techniques for detection of floods in Radar data
Flood	Klemas, 2015	Remote sensing of floods and flood-prone areas	Overview ofremote sensing and modeling techniques that enable scientistsand managers to evaluate the vulnerability of an area toflooding, determine the extent and intensity of the flooding, andassess the damage caused by the flooding event.
Drought	Belal, 2012	Drought risk assessment methods	Review paper of fundamental concepts of drought, classification of droughts, drought indices and the role of remote sensing and GIS
Drought	Senay, 2015	Drought monitoring and assessment	Selected examples of howremote sensing and hydrologic modeling techniques are being used to generate a suiteof drought monitoring indicators at dekadal (10-day), monthly, seasonal, and annualtime scales for several selected regions around the world.
Drought	Rhee et al., 2010	Drought monitoring and assessment using remote sensing	They present an index combining the land surface temperature (LST) data and the Normalized Difference Vegetation Index (NDVI) data from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, and precipitation data from Tropical Rainfall Measuring Mission (TRMM) satellite.

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Resilience

In the context of SES theory, **resilience thinking** addresses the cross-scalar dynamics and the development of complex socio-ecological systems while focusing on three main aspects**: resilience, adaptability and transformability**. **Resilience** refers to the capacity of an SES to remain within a stability domain despite of disturbances and perturbations (Folke et al., 2010). It can be defined 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 (IPCC, 2014b: 5). The resilience of an SES is closely connected with its **adaptability** and the collective capacity of its actors to influence and foster resilience through adaptive governance and resource management. Successful adaptation fosters the capacity of a system to adjust its responses to changing external drivers and internal processes and avoids its transition into an undesirable system state (Walker et al., 2004; Folke et al., 2010). The resilience of a system can be increased by influencing the location of the thresholds and by moving them or the system further away, by changing the ease at which thresholds can be reached or by managing cross-scale interactions (Walker et al., 2004; Kloos et al., 2015). Whenever the ecological, economic or social conditions of an existing system become undesirable or untenable, the level of transformability in an SES becomes crucial (Walker et al., 2004). Transformability refers to the capacity of the current system to create a fundamentally new system. It relies on all forms of capital, diversity in landscapes, seascapes and institutions, collective action and support from the governance at higher scales. Transformational change can be initiated at multiple scales whereas changes at lower scales can lead to feedback processes at a higher levels while eventually also facilitating transformational change at this scale. Transformations from one system to a more favorable one often occur by making use of a crisis as a window of opportunity for change (Folke et al., 2010).

Ecosystem robustness

Robustness is a concept that emerged in engineering and control theory and measures "the ability of a system to maintain itself within a narrow range of function and is ideally suited to problems that require careful setting of upper and lower bounds for system properties, such as optimal fisheries yield (Mumby et al., 2014)." It refers to the design of systems and can be used to describe cost- benefit trade-offs (Anderies, Janssen and Ostrom, 2004). The concept of resilience is actually related to robustness. But in contrast to robustness, resilience developed in ecology (Holling, 1973) applies well to describe the ability of a system to recover whenever a system modeling approach is required (Mumby et al., 2014).

Conceptual approaches and frameworks to vulnerability

During the past 40 years of vulnerability research numerous frameworks have been developed in order to operationalize and reflect the different perspectives and conceptual approaches towards vulnerability. Within this context, the **Pressure and**

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Release (PAR) model (Blaikie et al., 1994; Wisner et al., 2004), the **vulnerability framework by Turner** et al. 2003, the **BBC conceptual framework** (Birkmann, 2006), the **MOVE framework** (Birkmann, 2013b) and the **IPCC SREX framework** (IPCC, 2012b) are among the most influential concepts.

The **PAR model** largely reflects the ideas of **political economic thinking**. According to this conceptual framework, risk is viewed as the product of hazard and vulnerability whereas the vulnerability is generated by three progressive levels: root causes, dynamic pressures and unsafe conditions. The model explains why people are vulnerable and how underlying political and economic root causes generate dynamic pressures such as rapid urbanization and population change that translate into unsafe living conditions that are characterized by a lack of effective hazard protection (Wisner et al., 2004; Birkmann, 2013b). Effective risk and vulnerability reduction efforts thus need to allow for political and economic conditions at national and global levels (Birkmann, 2013b).

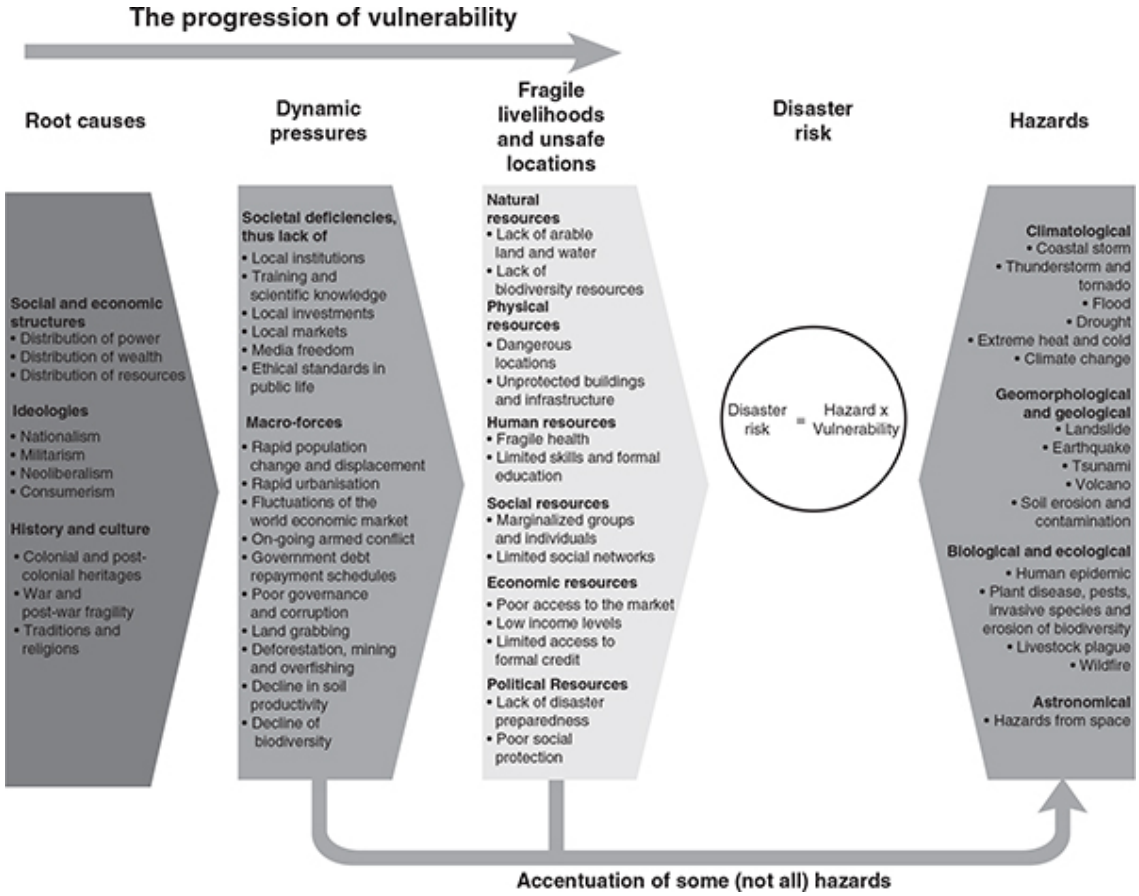

Figure 5: The PAR model (Wisner, Gaillard and Kelmann, 2012)

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By contrast, the **conceptual framework developed by Turner et al., 2003** represents **social-ecological thinking** and centers on the coupled human-environmental system in the vulnerability analysis. The framework accounts for the interactions of multiple hazards and differentiates between exposure as well as coping, impact and adaptation response as parts of vulnerability. In addition, different spatial scales are considered (Birkmann, 2013b).

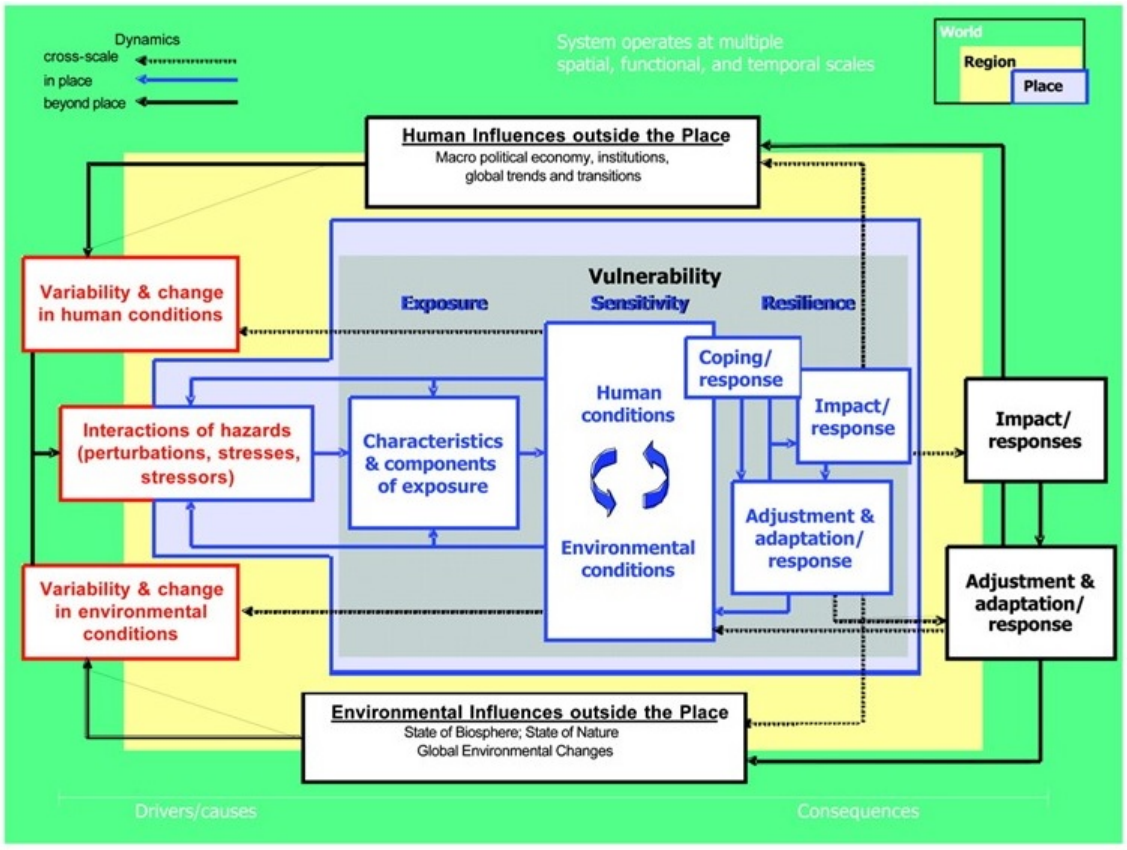

Figure 6: The vulnerability framework developed by Turner et al. 2003 (Turner et al., 2003)

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The development of the **BBC conceptual framework** (based on Bogardi & Birkmann, 2004; O.D. Cardona, 1999; Omar Darío Cardona, 2001) responded to the need for a holistic approach of **disaster risk assessment** while embedding vulnerability in the broader context of sustainable development. In this regard, three thematic spheres of sustainable development are distinguished: society, economy and environment. The risk arises from the interactions of a specific hazard with the three thematic spheres whereas exposure, susceptibility and coping capacities are differentiated as parts of the vulnerability. The BBC framework puts heavy emphasis on the dynamic nature of vulnerability and underlines the need to view vulnerability as a process. As well, it promotes a problem-solving perspective by analyzing vulnerability simultaneously with potential intervention measures within the social, economic and environmental dimensions (Birkmann, 2013b).

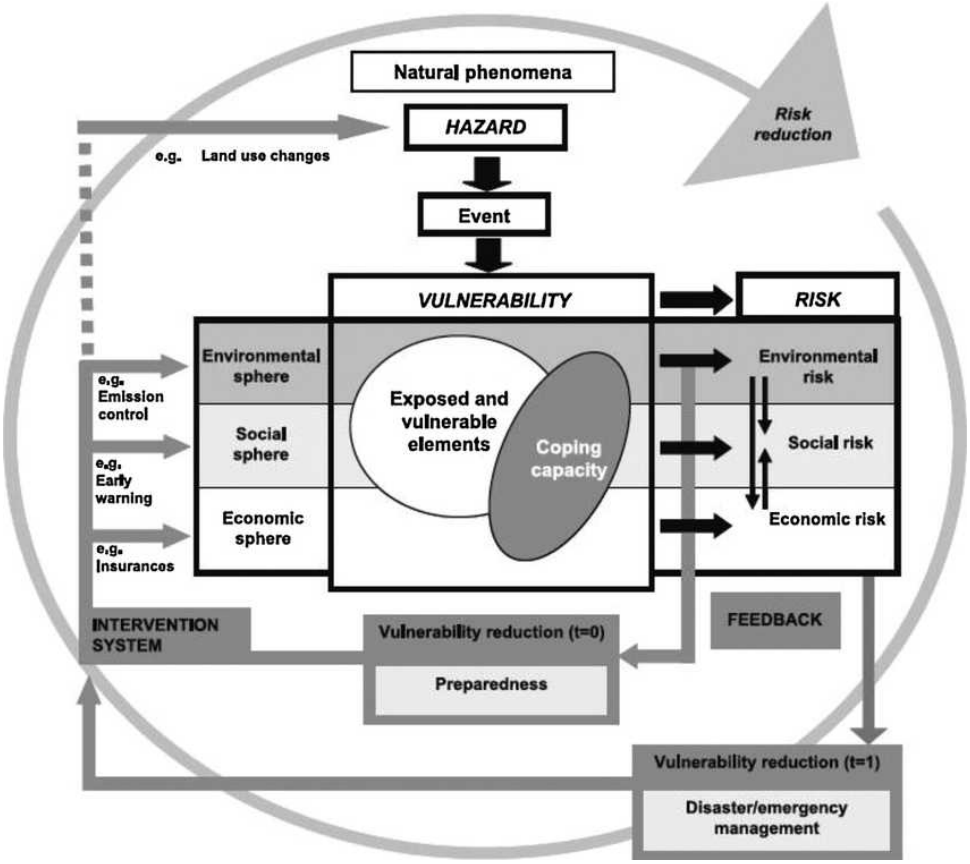

Figure 7: The BBC conceptual framework (Birkmann, 2013a)

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The **MOVE framework** (based on Birkmann, 2006; Bogardi & Birkmann, 2004; O.D. Cardona, 1999; Omar Darío Cardona, 2001; Carreno, Cardona, & Barbat, 2007; IDEA, 2005; Turner et al., 2003) amplifies the conceptualization of vulnerability as a dynamic process encompassing multiple thematic dimensions. According to the framework, risk is the result of interactions between hazards and vulnerable conditions whereas vulnerability is subdivided into exposure, susceptibility and lack of resilience. Beyond that, the MOVE framework takes up the newer discourse on **resilience and adaptation**. As such, it builds on the concept of coupled social-ecological systems and focuses on adaptation while referring to processes that promote transformation and system change. In contrast to adaptation, coping capacity refers to the ability to maintain a system as it is. The strong focus on risk governance and the response processes is characteristic for the framework (Birkmann, 2013b).

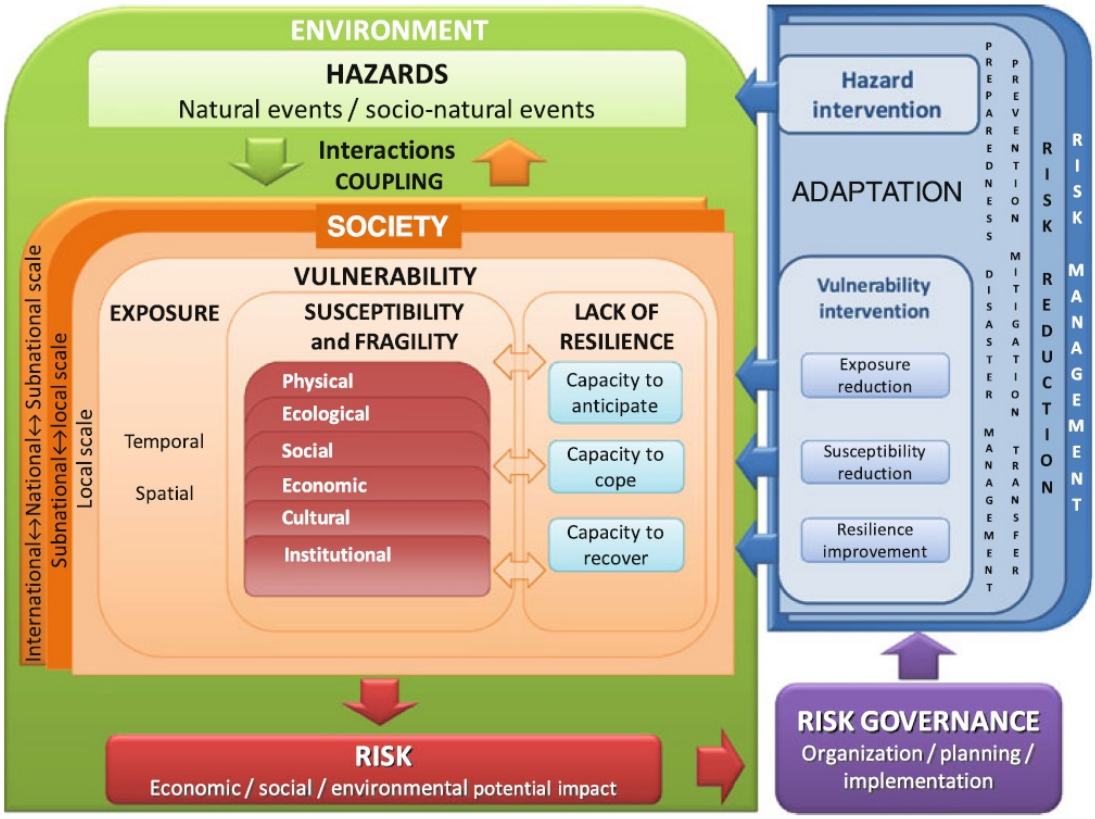

Figure 8: The MOVE framework (Birkmann et al., 2013)

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The **IPCC AR5 framework** (IPCC, 2014b) builds on the IPCC SREX framework and represents a consensus between the **disaster risk and climate change research community** (Birkmann, 2013b). According to the framework, disaster risk arises from the interface of weather and climate events and the exposure of vulnerable population and assets. The occurrence of climate and weather events is influenced by climate change and climate vulnerability whereas exposure and vulnerability are shaped by socio-economic development processes. Moreover, the IPCC AR5 framework illustrates that the development processes increase anthropogenic climate change and are influenced by the disaster risk at the same time. In contrast to other frameworks, the necessity to understand the changes related to the climate system and the development processes as well as their implications for the disaster risk is strongly emphasized (Birkmann, 2013b).

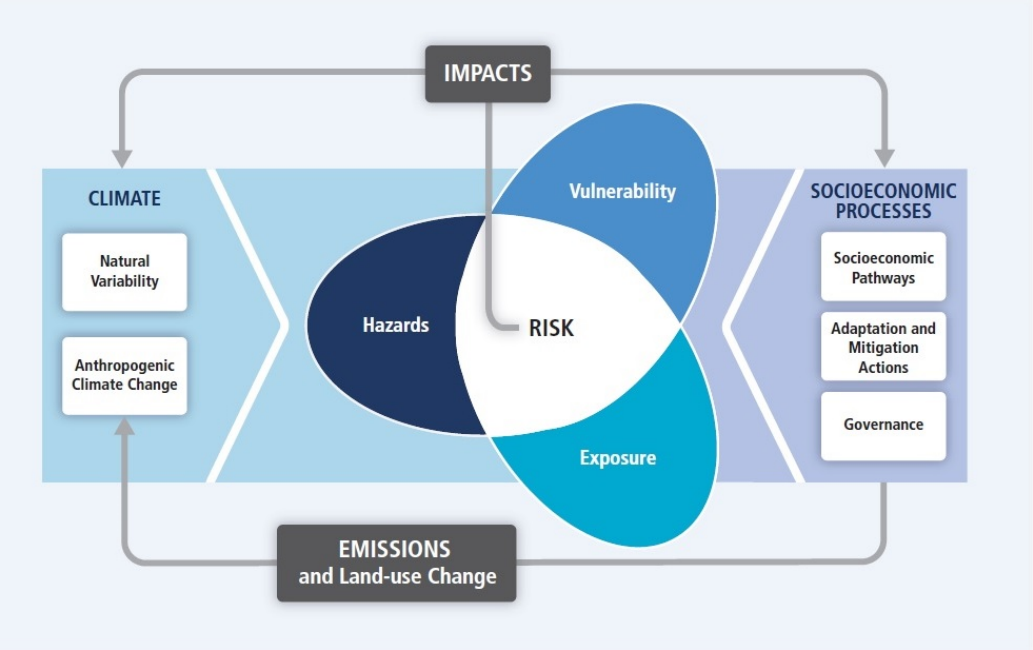

Figure 9: Core concepts of the WGII AR5. Risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems (IPCC, 2014b).

Key characteristics of vulnerability

There are currently more than 30 different methods and concepts on how to systemize vulnerability (Birkmann, 2013b). Nevertheless, vulnerability is today widely accepted to encompass **multiple dimensions** such as social, economic, environmental and institutional aspects, to be **dynamic** and to change over time as well as to interact across **multiple spatial scales** from local to international. The vulnerability that manifests at a specific spatial scale is thus the product of interrelations between different spatial scales and cannot be explained by ignoring these interrelations (Hufschmidt, 2011; Kloos et al., 2015). It follows that vulnerability is highly context-specific and differs from one location to another (Kloos et al., 2015). These key characteristics evolved over time and find different uptake in the individual conceptual frameworks.

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Table 9 Comparison of different conceptual frameworks in view of different key characteristics of vulnerability (adapted and modified from Hufschmidt 2011)

	PAR	Turner et al. 2003	BBC	MOVE	IPCC AR5
Context-specific	**X** (By the choice of factors pointing towards developing countries)	-	-	-	-
Dynamic	-	X	X	X	X
Multidimensional	X	X	X	X	X
Multi-scalar	X	X	-	X	-

Step 3.2 Assessing vulnerability

Framework West Sudanian Savannah Region

In order to enable the multi-hazard risk assessment in the West Sudanian Savanna Zone within the WASCAL project, a framework linking both vulnerability and resilience theory was developed: the "Multi-Hazard Risk Assessment Framework for the Western Sudanian Savannah Zone". This framework draws on the modified SUST Framework (Turner et al., 2003; Damm, 2010), the MOVE-framework (Birkmann, 2013b) and the Ecosystem Stewardship Framework (Chapin et al., 2010) and refines those by an explicit multiple hazard component.

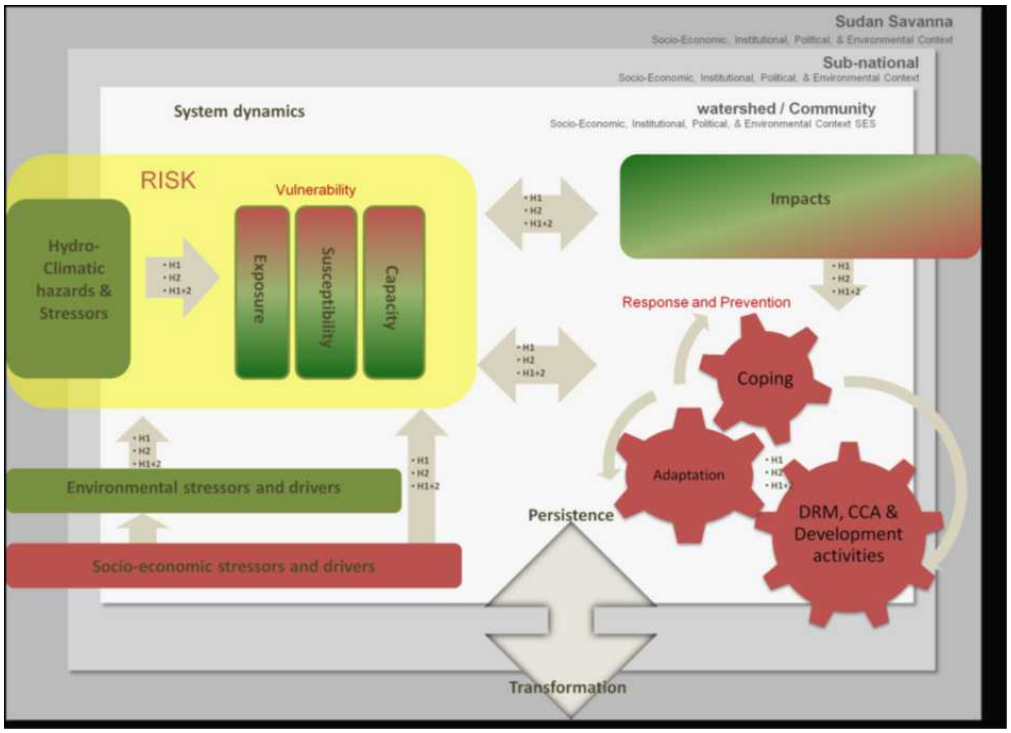

Figure 10: The "Multi-Hazard Risk Assessment Framework for the Western Sudanian Savanna Zone" (H: hazard, green: physical/environmental related, red: social system related); (Source: Kloos et al. 2015)

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This framework incorporates integral concepts of **vulnerability theory** by adopting **exposure, susceptibility and coping capacity**. By doing so, the framework enables the investigation of the conditions of the most vulnerable groups. The actual **risk** manifests related to different **hydro-climatic hazards and stressors** such as floods, droughts or more gradual climatic changes given the specific vulnerability of the exposed elements. In addition, the risk is influenced by **socio-economic and environmental stressors and drivers**. On top of that, the environmental stressors and drivers are likely to be affected by the socio-economic stressors and drivers at the same time. By triggering environmental changes that turn into hazards, the hazard component can be affected as well. In case of a hazardous event, risk will materialize in concrete **impacts**. Depending on the hazard context, different response and prevention measures are taken, including **coping, adaptation, disaster risk management (DRM), climate change adaptation (CCA)** as well as **development activities**. The Multi-Hazard Assessment Framework for the Western Sudanian Savanna Zone also ties to social-ecological thinking by incorporating the concepts of **resilience, persistence, transformation and cross-scale system dynamics** (Kloos et al., 2015). These dynamics are characterized by multiple interactions and feedback processes that act across multiple temporal and spatial (local, sub-national and regional) scales. Depending on its **resilience**, the system may **persist** and maintain its essential functioning and structure or **transform** and undergo essential change in key state variables, functions and structures. Disaster risk management strategies and adaptation through learning, innovation and experimentation contribute to a decreasing vulnerability and foster the persistence of a desirable system state. By contrast an increasing vulnerability may lead to an unintended transformation into an undesired system state by crossing a tipping point and by causing a regime shift (Folke et al., 2010; Kloos et al., 2015).

Step 3.2 – Option 1: Understanding vulnerability based on narratives

Retrospective analysis of vulnerability

In terms of their perspective, **retrospective and prospective study designs** can be distinguished. With regard to the WASCAL project, a **retrospective/ex-post perspective** was taken in order to gain an understanding on present day vulnerability and the manifestation of coping and adaptation in relation to floods and droughts. This perspective is particularly helpful to reveal realized vulnerability and actual coping and adaptation responses while drawing on the a-posteriori knowledge (i.e. knowledge derived from experience) of the interviewees. By contrast, vulnerability studies from an ex-ante perspective rely on estimates of coping and adaptive capacity that are not necessarily translated into responses. In fact, the translation of the capacities to cope and to adapt into coping and adaptation is surrounded by complex decision making processes that can only be revealed from an **ex-post perspective** (Pardoe, 2016). Even though, an understanding of these processes will be important to anticipate how decisions may be taken in response to climate change (Pardoe, 2016).

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Interview Designs: Semi-structured interviews

The design of an interview ranges along a continuum from fully **structured to unstructured. Semi-structured interview forms are situated in between the two ends of this continuum.** In structured interviews, the informants are exposed to the same stimuli and are generally based on a standard list of fixed questions. The aim of a structured interviews is to reduce interviewer bias while increasing the reliability and comparability of the responses (Russel Bernard, 2006; Mitchell and Jolley, 2013). By contrast, there is no imposed structure nor any set of standard questions in an unstructured interview. As a consequence, the interviewer bias might be high and the outcome might be too disorganized for a meaningful analysis. Even though, unstructured interviews can be an excellent tool for exploratory device or for building initial rapport with people (Russel Bernard, 2006; Mitchell and Jolley, 2013)(Russel Bernard 2006; Mitchell et al. 2009). Semi-structured interview forms have much of the freewheeling quality of unstructured interviews. They are open ended while still following an interview guide that includes a written list of questions and topics that need to be covered in a particular order. In addition, they involve a set of clear instructions (such as: ‘‘Probe to see if informants who have daughters have different values than people who only have sons.’’). By doing so, both reliability and comparability are increased. As well, a semi-structured design shows that the interviewer is prepared and competent without exercising excessive control (Russel Bernard, 2006)

Sampling Methods

There are numerous sampling schemes for drawing samples from the population and for selecting participants for the interview process. In the broadest sense, the existing methods can be classified into random/probability and non-random/non-probability based sampling schemes. Random sampling designs aim to select units with known probabilities so that the sampling properties (i.e. variance or standard error) of the estimators can be determined (COLOSS, 2017). Random sampling techniques are particularly suitable whenever generalizations are made (Lund Research Ltd, 2017). By contrast, these properties cannot be determined from samples that were drawn by using methods based on non-random sampling (COLOSS, 2017). In the following, stratified random sampling, purposive sampling and snowball sampling will be explained in more detail. Stratified random sampling belongs to the random based sampling methods whereas purposive and snowball sampling are non-random based schemes.

Stratified random sampling

Stratified random sampling is a random/probability sampling technique that splits the population into subgroups or strata while using stratification factors such as gender or geographical area that are related to the response variable or interest. In the following, single units are selected from the individual strata based on random sampling. As a probability based sampling technique, stratified random sampling allows for statistical conclusions while ensuring that all important population groups are represented. In addition, it allows the comparison between different strata (COLOSS, 2017). Stratified random sampling is relatively time-consuming and can only

be carried out whenever a complete list of population is available and if the population can be clearly delineated into different strata where each unit belongs to one single stratum. The sampling methods involves seven different steps including 1) the definition of the population, 2) choosing the relevant stratification, 3) listing of the population, 4) listing of the population according to the chosen stratification, 5) the choice of the sample size, 6) calculating a proportionate stratification, and 7) the sample selection based on simple random or systematic sampling (Lund Research Ltd).

Purposive sampling

Purposive sampling is a non-random sampling technique where the selection of the units depends on the judgement of the researcher. The main goal of purposive sampling is the selection of a population sample that best suit the research question. The resulting sampling is not representative and usually small. However, this is not regarded as a weakness. There are **various purposive sampling** techniques available such as maximum variation sampling that is used to capture a broad range of perspectives, **homogeneous sampling** that is used to sample units with similar characteristics, **typical case sampling** that is used to investigate normal/typical cases or **extreme case sampling** that is used to select special or unusual units (Lund Research Ltd).

Snowball sampling

Snowball sampling is a non-probability based sampling technique that is used to gain access to populations that are hard-to-find or hard-to-study.. This includes populations that contain very few members that are scattered over a large area, that exhibit some kinds of social stigma or that belong to an elite group. A snowball sample is created by first identifying one or more key informants in the desired population while subsequently using these informants to find further informants and so on till the final sample size is met. By doing so, the (initial) participants are asked whether they would be willing to help identify others that may be willing to take part in the study. One of the biggest risks of snowball sampling is to produce biased and non-representative samples. This is particularly true when the samples are drawn from large populations. By contrast, snowball sampling is an effective technique when the population is relatively small and likely to be in contact with each other. Moreover, ethical problem occur whenever potential informants are named that prefer to stay anonymous.. Since individuals are approached by other individuals with potentially similar traits, this sampling technique helps to break down some natural barriers that might be discouraging for taking part in the study.(Russel Bernard, 2006; Lund Research Ltd, 2017).

Step 3.2 – Option 2: Understanding dynamics of vulnerability based on scenario analysis

Selling livestock

Livestock resources was of central importance in order to cope with the losses that are incurred from climatic events. They were seen as a form of banking wealth and are regularly sold to facilitate recovery. This applied, for instance, to the replacement of damaged crops, the reconstruction and repair of flooded houses as well as healthcare cost that were caused or exacerbated by hazardous events. The choice of species and quantity to be sold was subject to complex decision making and included three major strategies: to sell the animal that best fitted the value that was needed, to select specific animals with the intent to minimize compound losses (e.g. by selling disease prone animals first, by selling males rather than females or by selling those animals that breed quickly) or to sell the animals that were most numerous with the latter strategy being as losses accumulated. As shown by the interviews, it took farmers three years on average to replenish the sold livestock. Given the potential for a flood or drought in any rainy season, households thus were at risk of facing a new hazard event before having completely recovered. From this perspective the sale of livestock leads to a protracted recovery that is appropriate to cope with present climate conditions but that might lead to spiraling decline under climatic change (Pardoe, 2016). Whenever livestock is sold to invest in adaptation, it could also be classified as adaptation strategy instead of coping mechanism.

Game components

The game components were designed to represent all key components of the socio-ecological system under investigation: **livestock assets, key crops, housing, climatic events and animal diseases**. By doing so, different images and colors were used to code the different game components.

With regard to the **climatic event and animal diseases cards**, a sun was chosen to depict drought conditions and a cloud with rain was chosen to depict flooding. These symbols were accompanied by the French and English words for “flood” and “drought”. Normal climatic seasons were represented by a smiling face and the word “normal”. Animal diseases were illustrated by means of simple pictures and cartoons of the individual animals under concern. Again, the silhouette or outline animals were accompanied by the English and French names of the respective animals.

For the **crop types** differently colored Lego bricks were used whereas each color represented a different crop type. For example, white bricks were used to represent cotton and yellow bricks were used to symbolize maize. Given the fact that cotton is seen as a white product and that maize is also called “yellow sorghum” these color schemes were chosen. **Groundnut, maize, sorghum and rice** were considered to be key crops in all three case study areas and thus always included in the game activities. In addition, two varying and case study specific crops were included. In the Beninese case study, cotton and yams were chosen, in Burkina Faso, cotton and sweet potato were incorporated and in Ghana, early and late millet were selected. Similarly to the representation of the crop types, differently colored mapping pins on cork boards

were used to represent **livestock**. In this context, yellow pins were chosen to symbolize chicken, green was used for goats, pink for pigs and blue for sheep.

The rooms comprising a compound were represented by mapping pins as well. Together with the pins representing the animals, they were placed on a cork board representing the homestead. Besides, a difference was made between the homestead and the farm whereas the homestead was understood as the place where the animals return at night and where the compound is located. By contrast, the farm was understood as the place where crops are grown and represented by a Lego board.

A **calendar** divided up in twelve monthly parts constituted another central element. The calendar was divided into two main seasons: dry and rainy season. Here, it was assumed that the dry season took place over four months and the rainy season took place over six months. At the end of the dry season one month was devoted for planting and at the end of the rainy season, one month was devoted for harvesting (Pardoe, 2016).

Additional details of the rules and regulations of the game

The **process of the game** was to move around the calendar, month by month, whereas climatic events took place in rainy season and the animal diseases took place in dry season. These seasonal patterns were revealed by preceding interviews and thus reflected reality. In addition, each **crop type was classified to be susceptible** within a particular month in rainy season. Whenever a hazard card was drawn within a particular month, the corresponding crop was affected. In order to determine the months when the crops were classified to be most susceptible and in a critical stage of their water needs, secondary information sources were consulted. In this context, different points in time were selected for each case study area (Pardoe, 2016).

Table 10: Susceptibility of crops per case study (Pardoe, 2016)

	Benin	Burkina Faso	Ghana
May	Yams	Sweet potato	Early millet
June	Rice	Rice	Rice
July	Groundnut	Groundnut	Groundnut
August	Maize	Maize	Maize
September	Sorghum	Sorghum	Sorghum
October	Cotton	Cotton	Late millet

The occurrence of climatic events and animal diseases was designed to take place at random. In order to simulate multiple hazard situations under climate change, the cards were weighted so that on average one flood and one drought occurred per year. The inclusion of both flood and drought events provides as well an excellent opportunity to discuss the different impacts of both hazards and to see whether one is seen as a greater concern than the other. The animal disease cards were weighted to an average of one animal disease per year. Moreover, different weights were applied to the individual types of animal diseases whereas pig diseases were most common, followed by chicken, followed by goat diseases. Sheep diseases were the least likely to occur. In doing so, findings from the preceding interviews were reflected (Pardoe, 2016).

Representation of prices

The crop values were based on real life crop prices. They were individually determined for each case study and derived from interview data and triangulated with secondary data from the FAO. Furthermore, the price of cotton was adjusted to reflect the profit after input materials while costs for fertilizer and pesticides where taken into account (Pardoe, 2016).

Table 11: Crop prices per case study (Pardoe, 2016)

	Benin (fCFA)	Burkina Faso (fCFA)	Ghana (Cedi)
Cotton	10,000	10,000	n/a
Early millet	n/a	n/a	150
Groundnut	15,000	15,000	200
Late millet	n/a	n/a	100
Maize	15,000	15,000	150
Sorghum	15,000	15,000	150
Rice	40,000	40,000	400
Sweet potatoes	n/a	20,000	n/a
Yams	20,000	n/a	n/a

Step 3.2 – Option 3: Quantifying vulnerability based on indicators

Calculating descriptive statistics

Descriptive statistics consist of methods for organizing and summarizing information. By contrast**, inferential statistics** serve to draw conclusions and measure the reliability of sample-based information (Weiss, 1999). The minimum, maximum, range, mean and standard deviation are among the most commonly used

measures of descriptive statistics. According to the Cambridge Dictionary of Statistics, these terms are defined as follows: $x = \frac{\sum_{i=1}^{n} x_i}{n}$

Mean: A measure of location or central value for a continuous variable. For a sample of observations $X_1, X_2, \ldots, X_n$ the measure is calculated as .

The mean is most useful when the data have a symmetric distribution and do not contain outliers.

Range: the difference between the largest and smallest observations in a data set.

Standard deviation: The most commonly used measure of the spread of a set of observations. Equal to the square root of the variance (Everitt and Skrondal, 2010). Based on these descriptive measures, outliers as well as indicators with a very low variance should be removed.

Bivariate correlation matrix

The relationship between a pair of variables can be measured by means of a bivariate correlation analysis. In order to do so, different indices can be used whereas the Pearson's coefficient (r) and the Spearman's rho coefficient (rs) are among the most popular. The **Pearson's correlation coefficient** is a measure of the strength of the relationship between two such variables while assuming that the variables are normally distributed and that their relationship is linear. By contrast, **Spearman's coefficient** assumes an arbitrary monotone association and can be applied when the Pearson's correlation coefficient is undesirable or misleading. The Spearman's coefficient is well suited to measure the strength of the relationship of both continuous and discrete data. It is thus also appropriate for variables that cannot be measured quantitatively (Hauke and Kossowski, 2011). The results can be illustrated by means of a matrix with rows and columns corresponding to the variables while the correlations between pairs of variables are displayed as off–diagonal elements (Everitt and Skrondal, 2010).

Rank to weight conversion

The rank to weight conversion model by Al-Essa 2011 was used to convert the expert rankings into weights. This model assumes a linear relationship between ranks and weights while assigning a weight of 100% for the first and most important indicator. The weights of the remaining r-ranked indicators can be assigned subsequently based on the following equation:

$$Wr=100-Sn(r-1)$$

Where Wr is the weight of the indicator, r is the rank, and Sn is the absolute value of the slope estimated by least squares regression when the number of indicators is equal to n (Asare-Kyei, 2017).

Part II

Intro-duction
Step 1 Planning the assessment
Step 2 Hazard assessment
Step 3 Vulnerability assessment
Step 4 Risk assessment
Refer-ences

Step 4: How to measure risk?

Step 4.2: Validation of risk based on the Community Impact Score (CIS)

Root Mean Square Error (RMSE) and the Coefficient of Determination (R^2)

Both, the Root Mean Square Error and the Coefficient of Determination measure the goodness-of-fit. R^2 is defined as the square of the correlation coefficient between two variables. It gives the proportion of the variation in one variable that is accounted for by the other (Everitt and Skrondal, 2010). It ranges from 0 to 1 and mathematically it can be calculated as $r^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$

whereas r^2 is the coefficient of determination, y_i is the observed variable and $\hat{y}_i$ is the predicted value (Barrett, 1974). R^2 is a relative measure.

By contrast, the RMSE is an absolute error measure that is based on the standard deviation of the residuals. It describes the differences between the model and the observations in the units of the model (Legates and McCabe Jr., 1999). Mathematically, it can be computed as RMSE= $\sqrt{\frac{1}{n}\sum_{i=1}^{n} e_i^2}$

whereas e_i is the model error (Chai and Draxler, 2014).

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VERSION I
(August 2017)

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