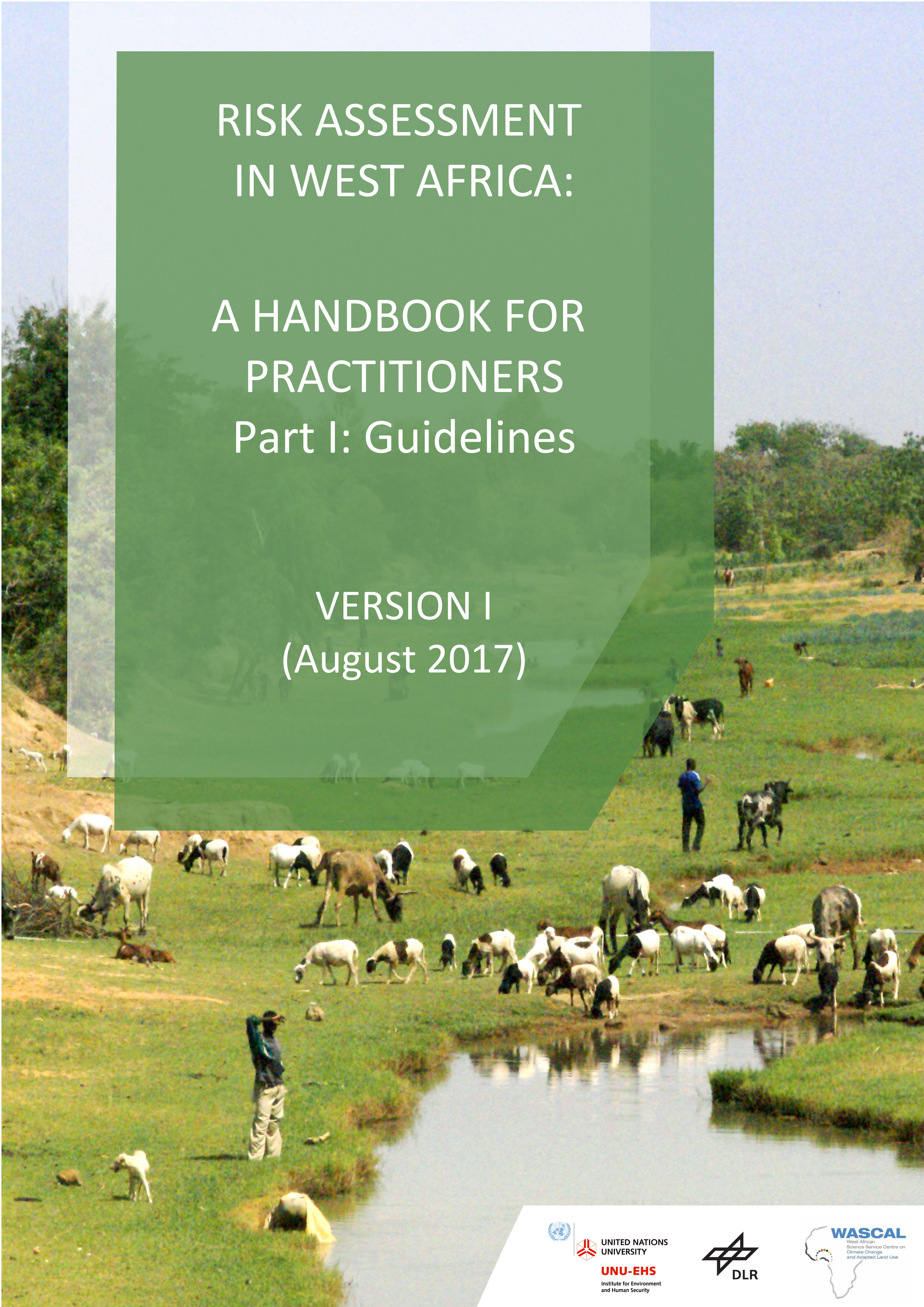

RISK ASSESSMENT IN WEST AFRICA:

A HANDBOOK FOR PRACTITIONERS
Part I: Guidelines

VERSION I
(August 2017)

UNITED NATIONS UNIVERSITY
UNU-EHS
Institute for Environment and Human Security

DLR

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

RISK ASSESSMENT IN WEST AFRICA: A HANDBOOK FOR PRACTITIONERS

Authors of this living document

Version I - part I, part II and report template (August 2017)

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Version II (tbd)

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West Africa has been described as a climate change hotspot with severe impacts due to climate-related natural hazards such as floods and droughts. For this region, it has been projected that the intensity of very wet events – leading to higher flood risks towards the late 21st century, will increase. In addition, more frequent extreme events are expected and the interaction of climate change with non-climatic stressors, such as diseases, economic turbulence, or lack of resources will aggravate the vulnerability of people and their agricultural systems in semi-arid West Africa.

This handbook for practitioners has been developed in the context of the West African Science Service Centre for Climate Change and Adapted Land Use (WASCAL) project funded by the Federal Ministry of Education and Research (BMBF) in Germany. The overall aim of this handbook is to promote and coordinate activities in the field of risk assessment within the West African region. The WASCAL Competence Center (CoC), representing the science service center of the WASCAL institution in Ouagadougou, takes the ownership of this handbook and integrates hazard, vulnerability and risk assessment in its institutional portfolio of its science-based services for the West African region. The scientific and technical background can be found in Part II.

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General Intro-duction

General introduction to the handbook

This handbook is structured into two main parts:

Part I represents the practical guidelines for assessing hazard, vulnerability and risk to climate-related hazards. A step-by-step approach explains the individual tasks and their specific procedures to conduct the assessment. The guidelines offer a selection between several options for specific steps of the assessment dependent on availability of resources and professional expertise. The guidelines are accompanied by a "report form", which helps conduct the risk assessment in a consistent manner and document the results in a uniform and structured way. The report form is directly linked to the step-by-step approach presented in Part I of the handbook.

Part II of the handbook provides scientific and technical background documentation for the practical guidelines. Each step of Part I is reflected by additional, more extensive documentation, scientific background, or links to additional resources. In addition, specific methodological procedures are explained in detail and scripts for automated procedures are provided.

The initial development of this handbook is based on the research results achieved mainly by the United Nations University – Institute for Environment and Human Security (UNU-EHS), in collaboration with the German Aerospace Center (DLR) and close cooperation with the WASCAL CoC, during Phase 1 of WASCAL from 2012 to early 2016. The research on risk assessment focused on rural areas in three specific case study sites, namely the Dano watershed in Burkina Faso, the Vea study area in Ghana and the Dassari study area in Benin (see details in Part II). This explains the fact that most examples of data, methods and results provided in this handbook are linked to these specific regions, and focuses on the natural hazards of floods and droughts. Nevertheless, the guidelines are written in a general way, so that the risk assessment procedures can be carried out for other hazards throughout West Africa.

This handbook is intended to be a "living document" hosted by the WASCAL CoC in Ouagadougou, Burkina Faso. In the process of using this handbook within WASCAL CoC, new examples, improvements and feedback will be

General Intro-duction

incorporated into updated Versions. WASCAL CoC, as provider of a Risk Assessment Climate and Environmental Service, is the first target group for this handbook, and governmental and non-governmental organizations involved in disaster risk management (DRM), disaster risk reduction (DRR) and climate change adaptation (CCA) within the West African region are the second target group, and end users.

This handbook will become a tool of the WASCAL's Risk Assessment Service in order to scientifically support national and regional risk assessment efforts and enhance adaptation and development planning. The end-users of the handbook will most likely be familiar with issues of climate change and risk to natural hazards, however, this book does not presuppose advanced scientific expertise in developing and conducting risk assessments. The continuous and participatory development of this handbook will ensure that the guidelines are kept practical, up-to-date and usable.

This handbook is particularly concerned with providing readily understandable, user-friendly guidance to develop and implement risk assessments considering the specific conditions which prevail in West Africa.

PART I

Practical Guidelines for Assessing Vulnerability and Risk to Climate-related Hazards

- Introduction: Understanding why and how to use the guidelines
- Step 1: Understanding and planning the vulnerability and risk assessment
- Step 2: Conducting the hazard assessment
- Step 3: Conducting the vulnerability assessment
- Step 4: How to measure risk?

Part I

Introduction: Understanding why and how to use the guidelines

Why are risk assessments important?

When a given region is severely affected by a drought, some people and ecosystems are more affected than others. Risk assessment helps to understand the specific reasons why. Only by knowing and understanding the specific reasons can counter measures such as specific coping and adaptation strategies be designed and developed. The following illustrated examples (Figure 1) show different situations that shape the vulnerability and risk of people and ecosystems to natural hazards, such as floods and droughts. While one smallholder (Figure 1: A) in this region is a subsistence farmer and claims the complete loss of the seasonally expected yield with no other resources than this, a second smallholder is a subsistence farmer, but with an additional income from raising livestock (Figure 1: B), and a third farmer has access to water for irrigation (Figure 1: C). Despite the fact that the same meteorological drought conditions hit these three smallholders, there is a strong difference in their level of vulnerability. Farmer A has the highest vulnerability and farmer C the lowest.

Detailed risk assessments are very important tools for DRM, first through planning efficient coping and adaptation measures to reduce the risk of natural hazards impacts (pro-active DRM approach). Secondly, they facilitate efficient relief in times of crisis (re-active DRM approach) by responding to specific human and environmental needs.

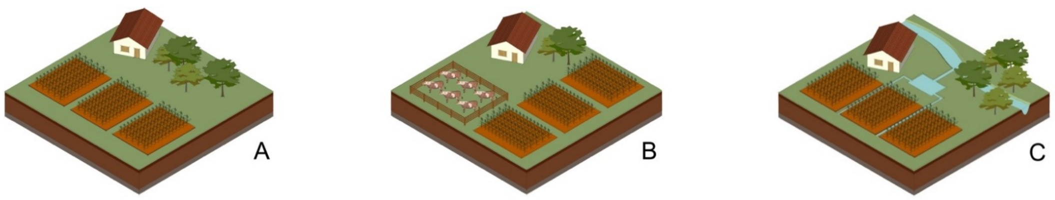

Figure 1: Examples of different situations that shape the vulnerability and risk of people and ecosystems: a) rainfed subsistence farm, b) rainfed subsistence farm with livestock, c) irrigated farm.
Source: Illustration by Samara Gomes, UNU-EHS

What is the purpose of the guidelines?

Part I of the handbook provides tools for planning and decision making by various stakeholders (e.g., the WASCAL Competence Center as main target group on the regional level as well as local authorities, community members, non-governmental organizations, academics, GIS experts) to conduct risk assessments. The specific purpose of the guidelines is to explain the scientific procedure for practitioners to ensure the consistent practice of the evidence-based risk assessment. These guidelines present a step-by-step approach to conduct the assessment and document the results in the report form. The current version of guidelines focuses on rural areas in the Sudan-Savanna ecological zone, but approaches can be applied for the West African region in general. Experiences in other agroecological zones should be communicated back to the WASCAL CoC for updating the handbook.

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Structure of the guidelines

The guidelines are structured as step-by-step approach. Each step will be introduced with explanations of the aims and outputs. For some steps, the handbook provides different options, which take into consideration different availabilities of resources or professional skills. In general, the number of tasks and outputs will depend on the assessment's objective and the time, skills and resources available.

How to use the guidelines?

To start planning and conducting the assessment, one must first read through the entire Guidelines. Becoming familiarized with the procedures will help practitioners take decisions based on the resources and expertise that they have available. Icons for the report form indicate where the different assessment tasks are matched in a documentation step in the report form. This will facilitate documenting each completed task in an efficient manner. Links to additional information, data sources, and methodological procedures in Part II of the handbook are also indicated by icons that link directly to their respective material.

Legend of icons

Report template	Link to a form for the documentation of each step of the assessment and their outputs.
Complementary literature	Link or reference to journal articles, books and other sources that can complement the information provided in the handbook.
Additional information	Information and tips that can contribute support the conduction of a task, usually located in the same page or section where indicated (look for the grey boxes).

(The icons are designed by Freepik and Nikita Golubev from Flaticon.)

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The "report form"

This report form is provided as part of the guidelines, but also as additional file (Figure 2). The general aim of the report form is to provide a consistent structure for documentation of assessment of results. At the same time, this structured report will deliver data to reinforce regional risk analyses for West Africa. Similar to the Guidelines, the report form is a "living document", which needs to be modified on a regular basis according to feedback from end-users and changes to the guidelines.

Report Template

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WASCAL RISK ASSESSMENT REPORT

Title of the assessment:	
Date (last modified):	
Filled by:	Affiliation:
Submitted to:	
Date of submission:	

Defining purpose and setting boundaries

Step 1.1 What is the purpose of the assessment?

Step 1.2 Which area will be assessed?

1.2.1 Check the box(es) that describe your study area.

□ Neighborhood(s)
□ City
□ Province
□ Country
□ Watershed
□ River basin
□ Urban
□ Rural
□ Other (specify): ______________________

Risk Assessment in West Africa: A Handbook for Practitioners WASCAL

Figure 2: The report template to document the results of the step-by-step risk assessment.

Step 1: Understanding and planning the risk assessment

Definitions and components of risk assessment

In this section, the most relevant terminology on risk assessment used in this handbook is explained in a generic manner. Detailed, scientifically-based definitions and other terminology can be found in Part II.

Hazard: An event that causes damage and crisis (example: a flash flood, a dry spell during a rainy season, etc.).

Multi-hazard: Multiple hazards that affect a region at the same time, or closely following each other (example: a flash flood that follows a drought).

Exposure: How elements (example: people, crops, livestock, houses) are exposed to a hazard in an affected area.

Susceptibility: How sensitive exposed elements are to hazard impacts (example: farmers without access to alternative incomes are more susceptible in a drought year).

Coping Capacity: What skills or resources people can use to reduce hazard impacts (example: farmers who have fields in different locations, and pastoralists who can move their herds are better able to cope with climate-induced crises).

Adaptive Capacity: The relevant resources and opportunities to adapt to certain hazards, exploit additional benefits, and reduce risk in the long term (example: farmers plant different fields and crops at different times as an adaptation to climate variability).

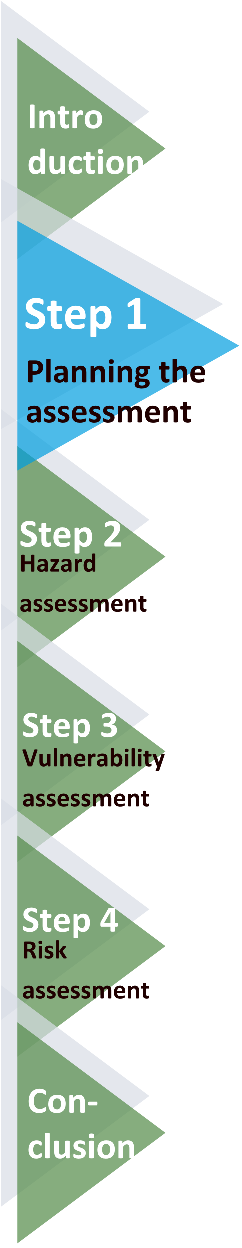
Vulnerability: Integrating exposure, susceptibility, and coping capacities to describe the specific characteristics of different elements (e.g., people, crops, livestock, houses) at risk of an expected natural hazard impact. Scientists have different views on the definition of vulnerability. More information is provided in Part II.

Risk: The combination of **hazard** and the different components of **vulnerability** as seen in Figure 3. Considering the above model, this handbook uses the formula: Hazard x Vulnerability = Risk. To accomplish a risk assessment, one must carry out both a hazard assessment (Step 2) and a vulnerability assessment (Step 3) before measuring or assessing risk (Step 4).

Defining purpose and setting boundaries

In the initial step of a risk assessment, the purpose, or objectives, of the assessment must be clearly defined, followed by setting the assessment's boundaries. This

Part I



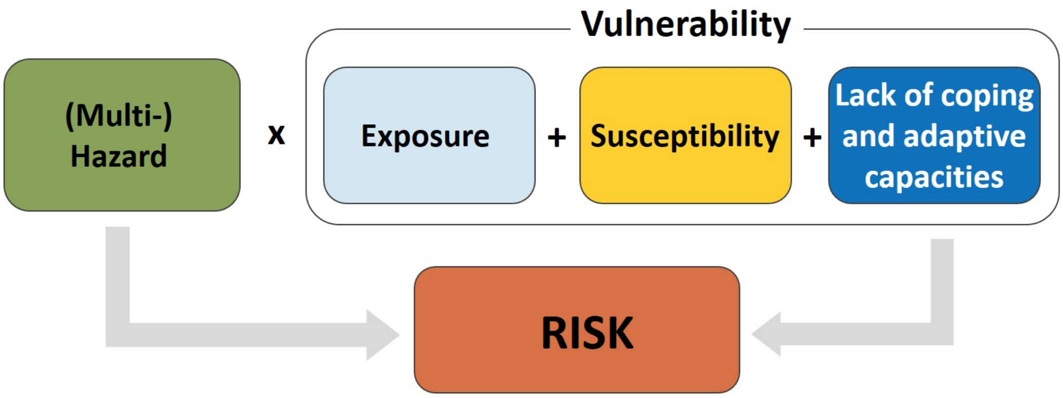


Figure 3: Components of vulnerability and risk and their integration.
Source: adjusted from Asare-Kyei, 2017

process will identify the needs to be addressed, define what results to deliver and estimate the work and resources necessary for conducting the assessment. It is also a chance to anticipate possible constraints and make adjustments to avoid or overcome them. With clear boundaries, time and resources can be planned and used more effectively and efficiently, contributing to the quality and success of the assessment. The following questions will help you defining the purpose and boundaries of your assessment.

Step 1.1 What is the purpose of the assessment?

The purpose of a risk assessment can be manifold – depending on the context of the assessment and the endusers of the assessment results. Examples of different purposes are:

- To provide policy makers and practitioners of different sectors with a systematic risk analysis in the context of climate change to support the planning of adaptation strategies or the allocation of disaster risk reduction measures.
- To support local and national disaster managers in identifying a set of indicators relevant for assessing risk at multiple scales.
- To provide the methodological basis for future studies of risk of multiple hazards. This will require a dynamic approach, continually updated with new data.

Please document briefly the purpose of your risk assessment

Step 1.2 Which area will be assessed?

Next, the spatial boundaries of the assessment should be set. They might coincide with physical-geographical boundaries (e.g., watershed, river catchment, river delta, etc.), political-administrative divisions (e.g., city, districts, province), or social-geographic regions (community, rangeland). Then you need to consider which characteristics within the defined boundaries are relevant for your assessment. For example: you might focus on rural or urban areas, or both. Check the boxes in the report template to indicate the selection that fits to your defined area, or add new characteristics if those relevant to your assessment are not listed.

Box 1: Creating an image of your study area:

a) Online in Google Maps:
- Bring up Google Maps on your computer (https://www.google.de/maps/)
- In the search box (left upper corner), type a reference to help you localize your assessment area (e.g. town, district).
- Use the buttons + and – (right bottom corner) to zoom your image in and out. Adjust the view by left-clicking on the image and moving the mouse around.
- By clicking on the left bottom side of the screen, you can alternate between a map and an aerial photograph (earth) view. Choose the one that gives you the best view for your needs.
- Once you have framed your study area, take a picture of it by pressing the “print screen” button on your keyboard. This will copy the image.
- Paste the image into your profile template by pressing simultaneously the keys ctrl + V.
- Trim unnecessary elements from your photo using the “crop” tool under the “picture format” tab.
- Draw the borders of your study area using the freeform tool. You will find it under the insert tab> shapes > lines > freeform. To remove the shape fill, go to shape format > shape fill > no fill.

Required resources: Computer, internet connection, Google Earth app

b)Using the Google Earth app:
- Click here (https://www.google.com/earth/desktop/) and follow the instructions to download the Google Earth Pro app for free.
- Open the app.
- In the search box (left upper corner), type a reference to help you localize your assessment area (e.g. town, district).
- Use the buttons + and – on the right side of the screen to zoom your image in and out. Adjust the view by left-clicking on the image and moving the mouse around.
- Once you have framed your study area, add a polygon to design its limits by clicking on the icon on the upper toolbar.
- In the dialog box, name your polygon. You can change the style and colors of the shape in the equivalent tab (Style, Color). To be able to see the assigned area, select the option “outlined”.
- Now move the dialog box to better visualize the image (click on the title bar with the left mouse button, hold and drag) and click on it to draw your polygon. Each click will correspond to one of the polygon's corners.
- Once you are done, press ok on the dialog box.
- Save the image to your computer by clicking on “File > Save > Save image”. You can then insert this photo into the report template!
- To be able to open and modify your selection later, you will need to save this map as a *.kmz file. Click “File > Save > Save place as” and type a name for your map image.

To situate your area in relation to other WASCAL countries, please mark your selected area on the map provided in the report template. If you follow the instructions in Box 1, you can create an image of your study area with Google Maps or Google Earth to visualize the assessment area in more detail. This spatial visualization will help you become more familiar with the area and understand its geographical setting.

Step 1.3 What system components will be assessed?

Depending on the purpose of the study, you need to decide the unit of analysis. As examples:
- If you want to assess how many people are affected by a certain hazard, individual people or people within communities will be the unit of analysis.
- If you want to assess the economic loss of a certain region due to a hazard, the unit of analysis might be infrastructure (buildings, roads, irrigation systems) or livelihood assets (crops, livestock, trees) in the selected region.

In most cases, however, you will want to understand the impacts of hazards for a specific region in general. Because most processes in society and the environment are

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strongly interrelated, with dependencies and cascading effects, you will need to assess multiple components in the social-ecological system (SES). An SES perspective includes societal (human) and ecological (biophysical) subsystems and their mutual, emerging interactions. More information on SES and examples of their design can be read in Part II. Check the boxes in the report template to indicate which system components will be assessed in your study.

Step 1.4 Which sectors need to be involved?

Natural hazards usually impact multiple sectors at the same time. Therefore, it is important to reflect on sectors being affected and decide which to consider in the risk assessment, and which stakeholders to select in the future steps for the participatory steps of the assessment. The participation of stakeholders from different sectors is essential to gain a holistic understanding of the multiple dimensions of study area's vulnerability. Examples of relevant sectors are illustrated in Figure 4 and further explanation on the involvement of different sectors in disaster risk reduction is detailed in Part II. Chect the boxes in the report template to indicate which sectors need to be involved in your study.

Figure 4: Examples of sectors that are relevant to consider in the risk assessment (Source: designed by Freepik from flaticon.com.)

Step 1.5 What time f rame will the assessment use?

At this point, you need to define the period of time you want to consider for the assessment. The time frame of a hazard assessment (see Step 2) will depend on the period of the hazard event or events (e.g. flood or drought events) under study. For a vulnerability assessment (see Step 3), characteristics such as socio-economic circumstances (e.g. poverty rate, literacy rate, gross domestic product) should also overlap with the time period for the assessment. The ideal case would be that all assessment time frames coincide, but in practice, it often happens that the time frames of the individual risk components (i.e. hazard and vulnerability assessments) do not match with each other, or only partially overlap. The main reason for this mismatch is the limited availability of data. Note the planned time frame for hazard and vulnerability assessments in the report template.

Step 1.6 Human resources and prof essional expertise

The risk assessment can be conducted following different steps and pathways, depending on available expertise. Box 2 summarizes different expertise relevant to the various steps of the assessment. Please make a list of available expertise (see Box 2) and human resources (e.g. number of people, full-time or part-time) available to you

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for the assessment in the report template.

The availability of human resources and professional expertise will affect the level of detail and the complexity of the risk assessment. It is important to have this information ready for planning the next step: the detailed work plan.

Box 2: Specific expertise for risk assessment:

- Disaster risk management
- Geographic Information Systems
- Remote sensing analyses
- Social surveying and other social science methodologies
- Participatory approaches, including Action Research, Participatory GIS (PGIS)
- Livelihood analysis
- Others (to be specified)

Step 1.7 Work plan

After you have read through and understand the guidelines, make a detailed work plan and estimate the necessary time for the completion of each task. This will enable you to estimate how long the assessment will take and what human and financial resources will be needed. If you already have a clear deadline for submitting the report, and/or a defined limit of available resources, the time and resources should be carefully distributed to the individual tasks. If you realize that you don't have enough time and/or resources, you should adjust the objectives and expected outcomes of the project. If you create milestones throughout the detailed work plan you can easily follow the progress. Document the envisaged timeline and tasks to be completed in a specified time frame in the report template.

Step 1.8 Financial and material resources

Document the financial and material resources required to conduct the assessment based on the detailed work plan. It will also be helpful to list the necessary material and other resources and plan for these in the budget, accordingly.

Step 1.9 Who should be consulted during the assessment?

List the individuals, groups and organizations who might hold relevant information regarding the topic and selected region of the risk assessment. Examples are (i) longtime residents in exposed areas to investigate people affected by hazards in the past, (ii) governmental stakeholders, at different levels, involved in disaster risk management and spatial planning, and (iii) NGOs and companies working in the area. This information will be used for the vulnerability assessment (see Step 3). A list of relevant institutions that were involved in the risk assessment approach outlined in this handbook is provided in Part II.

Step 1.10 Who will be the end user of the assessment?

Definition of the end users is linked to the assessment's purpose. There may be more than one group of end users with different needs (example: a municipality and a national-level agency). At this stage, it is important to discuss and clarify who will receive the assessment report, and what might their next steps be. If end users are consulted and their information clarified during the planning phase, the results of the assessment can be well planned and adjusted to their needs and the way they will use

the report. Document in the report template the target groups that benefit from the results of the assessment.

Step 1.11 What outcomes do you intend to deliver at the end of the assessment?

Each phase proposed by this handbook is composed of tasks, which will produce specific outcomes. As described above, different options can be taken to accomplish the main steps of the risk assessment, depending on the purpose of the study (see Step 1.1), or the availability of professional expertise and human resources (see Step 1.6). Both the hazard assessment (Step 2) and the vulnerability assessment (Step 3) will provide several options to follow, which lead to different outputs. In the hazard assessment, you will see that different methods are suggested to assess hazards, namely (1) hazard event inventory and remote sensing based hazard mapping, (2) participatory hazard mapping. At this stage, it is important to identify and plan the different methods you will use depending on the purpose and objectives of the assessment, availability of expertise and resources, and the target group of the assessment. Box 3 summarizes the outputs that can be derived from the individual steps and options provided in this version I of the handbook. Check the boxes in the report template to indicate which outputs will be delivered by this assessment.

Box 3: Overview of outputs that are suggested in the diff erent stages of the assessment

1.) Hazard extent map (see Step 2.2- Option 1-3)
2.) Hazard severity map (see Step 2.2- Option 1-3)
3.) Hazard event data base (see Step 2.2- Option 1)
4.) Web of impactson vulnerability to multiple hazards (see Step 3- Option 1)
5.) Coping and adaptation strategies based on scenarios (see Step 3- Option 2)
6.) List of vulnerability indicators (see Step 3- Option 3)
7.) Vulnerability map of the study area (including maps of vulnerability sub-components) (see Step 3- Option 3)
8.) Risk map of the study area (see Step 4)
9.) Risk profiles for the sub-units of the study area (see Step 4)

Step 2: Conducting the hazard assessment

When the assessment planning is completed, the practical part of the assessment can be initiated. It is recommended that you start by identifying those hazards that might affect the selected area and will be considered in the assessment. Important aspects to consider with regard to a single hazard assessment versus a multi-hazard assessment can be found in Part II.

Why is hazard assessment so important? If we know

- WHERE a certain hazard (e.g. a flood or drought) can occur
- HOW OFTEN a certain hazard affects the same region
- HOW INTENSE is a certain hazard impacting a region,

we can understand the hazard context: the first important piece of knowledge to understand the risk of the potential hazard impacts due to this hazard in the defined area.

The characteristics that generally describe a natural hazard event – frequency and intensity – vary strongly between locations. This means that you will need to conduct the hazard assessment using maps and locate the hazard characteristics in a spatially explicit manner. From Step 2.2 onwards, you will have three options to choose from to conduct a spatially explicit hazard assessment – depending on your availability of resources and professional expertise.

Step 2.1 Defining the natural hazard under consideration

Natural hazards have different causal factors and a mixture of it. To give some examples, meteorological factors can lead to flash floods, thunderstorms or droughts; hydrological factors can lead to river flooding; biological factors can lead to epidemics of diseases; and geological factors can lead to landslides or earthquakes. A detailed definition of natural hazards can be found in Part II.

In West Africa, floods and droughts are the most frequent climate-related hazards, although many other hazards occur in the region. Climate change in West Africa is likely to cause more seasonal variability. Increasing disruptions to rainy season precipitation will likely result in more frequent floods and droughts; some may occur in succession within a single rainy season.

In this step, it is important to clearly define the type(s) of hazard(s) that will be observed and integrated in the assessment. This will be the basis on which the measurements to assess hazard will be designed in Step 2.2.

a. Drought

A drought is an extended period of unusually low precipitation that produces a shortage of water for people, animals and plants. It develops slowly, sometimes over

years, making its onset difficult to detect. Although referred to as natural hazards, droughts can be exacerbated by human activities such as deforestation, modification of water bodies and overexploitation of water. Please see a detailed description on different types of droughts in Part II.

b. Dry spell

In contrast to drought, a dry spell is a shorter period of unusually dry conditions, e.g. when rainfall is interrupted for more than a week during the rainy season, and seriously affects crop development. There are different terminologies used for dry spell, such as “mid-season drought”, “hybrid rainy season”, etc. Please find more information on this in Part II.

c. Flood

Flood is a general term for water overflowing the banks of a river, lake or other body. Depending on where and in which context this occurs, a flood has different specificities.

- Standing flood: water covers normally dry land for more than a day, and sometimes several days;
- Riverine flooding: water overflows from a stream or channel onto normally dry land in the floodplain;
- Coastal flooding: higher water levels than normal occur along the coast;
- Fash flood: water ponds and flows on land at a certain place due to accumulated heavy rainfall. Flash floods occur suddenly and last for a relatively short period of time. They can occur in areas outside the area of rainfall.
- Deluge: an extremely heavy rainfall causes destruction, and flows away into normal or seasonal water bodies. A deluge can cause a flash flood outside the area of rainfall.

Please document which of these or other hazards are relevant in your study area in the report template, and highlight the specific hazards that will be considered in the assessment.

Step 2.2 Assessing hazards

Assessing a hazard means locating where a certain type of hazard (e.g. a flood or drought) may occur, measuring how intense it might be, and estimating when and how often it is likely to occur. Usually a retrospective assessment is conducted, meaning information is collected, and measured if possible, on historical hazard events in the study area. One can also take a forward-looking perspective by modelling the probability that certain hazards may occur based on given environmental conditions. At this time the guidelines present only retrospective

approaches to assess hazards. After you decided which hazard(s) will be considered for the assessment, you will follow general steps to assess them:

(1) Mapping the spatial location of the hazard event (see also Step 1.2). To locate the assessment, it will be very advantageous to have detailed maps of the selected study region from the beginning, and for all of the options.
(2) Measuring the frequency of the hazard event over a certain period of time (see also Step 1.5).
(3) Identifying characteristics to measure the severity/intensity of the hazard.

In the following steps, three options are presented for conducting a hazard assessment, with clear indications as to what expertise and resource will be needed, and what outputs will result from the individual assessments (see Table 1). Check the boxes in the report template to indicate which option(s) will be used for the hazard assessment.

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Table 1: Overview of three different options to follow for conducting a hazard assessment.

	Hazard assessment		
Option	**Hazard event inventory**	**Participatory hazard mapping**	**Remote sensing based hazard mapping**
Activities	1. Collect data on hazard events and impacts from local, regional and national disaster risk management agencies and other databases. 2. Establish a database to store data in a structured way. 3. Insert data into database. 4. Synthesize and document results of data collection.	1. Prepare detailed maps of localities within the study area. 2. Visit communities to ask community members to show the areas where hazard(s) have been observed. 3. Draw the boundary of the observed hazard area on the map. 4. Document the time period and impacts of the event observed by community members	1. Identify appropriate Earth Observation (EO) data. 2. Acquire selected EO data. 3. Process EO data to detect hazard events (including spatial extent), quantify duration and frequency of hazard events and assess hazard severity. 4. Culculate hazard characteristics 5. Validate 6. Interpret and document resulting maps.
Output	• (Electronic) Database • Number of events per locality. • Impacts of hazard events per locality.	• Maps which illustrate the observed hazard extent. • Number of events per locality. • Impacts of hazards per locality.	• Geographic Information System with information layers on hazard events, hazard frequency and hazard severity. • Maps of hazard characteristics. • Documentation and interpretation of hazard maps.
Prof essional expertise needed	• Basic computer skills • Basic calculation skills	• Reading and interpretation of maps • Participatory approaches • Basic calculation skills	• Advanced computer skills • Skills in geospatial data processing and remote sensing image analysis
Resources needed	• Computer, software to build electronic databases	• Detailed maps that cover the study area	• Computer software to process spatial data

In the following, the individual options are described in more detail and links to relevant resources, scientific and technical background information provided.

Step 2.2 – Option 1: Hazard event inventory

Please read throughout the four tasks and then design your approach for collecting, structuring and storing data.

1. Collect data on hazard events and impacts f rom local, regional and national disaster risk management agencies and other databases.

There are different opportunities to collect data on hazard events. The most reliable data usually come from the local, regional and national disaster risk management agencies of the selected study region. Please find a list of disaster risk management agencies in Table 2 provided in Part II. You might also find data by reviewing existing databases that store hazard event information for the selected study region. Please find a list of relevant data sources in Table 3 provided in Part II. List potential data sources, contact information and details of the available data in the report template.

2. Establish a database to store data in a structured way.

To store the data and make use of the data in an efficient manner, we strongly recommend that you create an electronic database that will hold the data in a structured way. Design an appropriate structure of your data, which reflects the purpose of the study and captures all details of accessible data. A structured template for data entry will allow you to preserve the specific format and consistent units for future queries within the database.

Note: Each data entry must have spatial information linked to it. This might be the name of a town, community, or district, but most preferred are the geographic coordinates of the hazard event's location. More information on geographic coordinates and GPS mapping is provided in Part II.

You must consider how this data is to be shared with other practitioners or researchers. Only if data is stored in an electronic format, with a clear structure, can it be shared and used for multiple purposes and assessments. A selection of open source and licensed software designed to build databases is provided in Table 4 in Part II. The "Resources" folder also provides a structured template of an MS Access database, which was developed by UNU-EHS during the WASCAL CRP WPS (Event_database_template.mdb).

3. Insert data into database.

Insert the data into your database in a careful and consistent manner, taking care to preserve the structure and format of the database. We recommend to conduct a quality check by another person.

4. Synthesize and document results of data collection.

Without synthesis, this collection of data in your database has no clear information. To perform additional analyses and synthesize the relevant characteristics of the hazards

events, we recommend that you sum up the number of events per locality to obtain an indicator of hazard frequency per locality. The impacts of hazards are an important indicator for hazard intensity and provide an important reference for evaluating overall risk (see Step 4.2 – Community Impact Score). Document the results of the data analysis in the report template.

Step 2.2 – Option 2: Participatory hazard mapping

Participatory mapping aims to enlist local communities to help document hazards that have affected them and their area.

1. Prepare detailed maps of localities within the study area.

Before beginning participatory mapping, you need to acquire detailed maps (e.g. local topographic maps, print out of zoomed area in Google Earth) of the selected study area. Such maps can be either prepared based on geospatial data, downloaded from internet map providers, or accessed via local or national geographical services. It is recommended to obtain or prepare maps with a high level of detail, where features such as settlements, roads, rivers, lakes, and forests can be recognized in the map. A legend should clearly illustrate how the features are displayed in the map. The extent of the map must cover the locality of the community of the mapping participants, as well as impacts of hazard events under study. Multiple copies of the maps can be distributed among the different participants of the mapping exercise.

2. Visit communities to ask community members to show where hazard(s) have been observed.

Which communities are selected for the participatory mapping depends on the purpose and design of the assessment. In general, this approach is only appropriate if a local scale risk assessment is envisaged and specific areas are targeted for an assessment. It will be difficult to cover larger areas with participatory hazard mapping.

The participatory mapping can either be conducted through focus group discussions or working with individuals who experienced the hazard event. We recommend that you accompany mapping exercise participants to the affected location, and let them describe exact details on the extent, duration and impact details of the hazard event. For practitioners more skilled in participatory approaches, methods such as transects and Participatory Geographical Information Systems (PGIS) will be helpful here. More information on PGIS is provided in Part II.

3. Delineate/draw the boundary of the observed hazard area on the map.

The information from the participatory mapping should be directly drawn into the maps that were obtained or prepared for this assessment, either by the community

members or by the participatory mapping facilitator. The most important information to be integrated into the map is the spatial extent of the hazard. Additional information, such as severity, or specific features (fields, roads, houses) that were more heavily affected can be indicated on the maps with different colors or styles of delineation or marking. Make sure to record the meanings of these different delineations or markings in a key or legend.

4. Document the time period and impacts of the event observed by community members.

On a separate sheet of paper, take note of all details participants mention about the impacts of the hazard events, such as yield loss, collapsed houses, livestock loss, diseases, no access to schools, etc. These are essential to acquire a more comprehensive picture of natural hazard risk, and will help to validate the risk assessment later. If the spatial extent is known, link the impact information to the spatial area, either by taking the coordinates of affected features, or marking the features on the maps. More details on further use of data for validation are explained in Step 4.2 (Validation of risk based on the Community Impact Score (CIS)). Summarize the results of the participatory hazard mapping in the report template for the respective locations that are part of the assessment.

Step 2.2 – Option 3: Remote sensing based hazard mapping

The remote sensing data analysis needs to account for the following tasks:

1. Identify appropriate Earth Observation (EO) data.

Different remote sensors (active, i.e. sensors provide their own energy for illumination and measure the radiation reflected vs. passive, i.e. sensors measure the reflected sunlight) acquire various Earth Observation (EO) data types. Selection of the sensor to be used depends on the type of hazard, the spatial detail needed, and the area of interest. If the area of interest is small (e.g. a city), we recommend high resolution data in the dimension of <5 meters, but for a comparatively large area (e.g. a country) medium to low resolution data in the range between 30 to 1000 meters are sufficient.

- **Drought**

Since the detection of agricultural droughts using remote sensing is based on the different spectral signatures of healthy and stressed vegetation, optical EO data are needed for the approach suggested here. Optical sensors have the disadvantage that no information can be obtained during cloudy conditions. Nonetheless, weekly composite images can be used to close data gaps resulting from clouds. Due to the slow onset and relatively long duration of droughts, these weekly composites are able to show different plant growth stages well enough. To capture the different phenological stages though, a temporal resolution of one week or less is recommended.

Droughts in this handbook are defined as a deviation from a long-term average. Consequently, a long time series (at least 30 years) is necessary for drought determination and finding drought thresholds. At present (2017), the Advanced Very High Resolution Radiometer (AVHRR) instruments, which began recording in 1981, are the only sensors having sufficient historical data for drought hazard assessment. Though the spatial resolution should be as high as possible, this will be limited for much of West Africa due to the necessary 30 years for the time series. The AVHRR raw data has a resolution of approximately 1.1 km, the processed data recommended in this approach has a resolution of 4km.

Box 4: Selection of remote sensing data for

1. Drought Hazard Assessment:
- Optical data
- Long time series necessary to establish "normal" condition (at least 30 years)
- Temporal resolution at least weekly
- Spatial resolution as high as possible, but often limited by other criteria

2. Flood Detection:
- (Very) high resolution optical or radar data

For your drought hazard assessment, we suggest that you use an index from the reflectance values that represent plant vitality. The main advantage of this approach is that no preprocessing of raw data is necessary, and the relevant information from the images has already been extracted.

- **Floods**

Floods are relatively short events, so a satellite image acquired during and/or shortly after the peak of a flood event is required to obtain up-to-date information. In such cases, a request is normally sent to a satellite image provider (e.g. DigitalGlobe) to point a satellite sensor to the flooded area (also called satellite tasking) in order to obtain an up-to-date image. Alternatively, if an image has coincidentally been acquired from the area, it can be requested/purchased. Note, however, that satellite tasking tends to be a bit more expensive than acquiring images through the normal process. Both radar and optical data can be used for flood analysis.You should aim to capture data at flood-peak (determining this, perhaps, by weather forecasts). If the flood lasts for more than a day, it will be useful to follow flood development through daily image acquisitions.

If appropriate data from satellites are impossible to capture (e.g., appropriate spatial resolution is not available, or optical data not usable due to cloud cover), you should begin tasking and data acquisition from other satellites as soon as possible after the event. Because data from commercial providers might be costly, for major events you should send a request to the International Charter – Space and Major Disasters, which provides satellite images as well as value added products free of charge (www.disastercharter.org).

Radar data are often the first choice for floods, because (1) radar sensors acquire usable data regardless of weather conditions (i.e., cloud cover has limited effect on radar systems), (2) data with high spatial resolution are available, which allows the detection of even smaller flooded areas, and (3) data can be recorded in remote and rural areas (e.g. study sites). The major disadvantage of these data is that availability is very limited for past events as continuous recording is not carried out. Another disadvantage is that they have limited use in urban areas and deserts due to radar geometry. In that case, we recommend a combination of radar and optical systems. Document the data needs available resources for data acquisition, resolution and area to be coverd in the report template.

2. Acquire selected EO data

Selected EO datasets can be ordered either by commercial satellite data providers or from data hubs providing the data for free.

To acquire satellite data from the internet, follow these steps:

(1) Select the desired spatial extent: Often different options for entering the area of interest (AOI) are given such as (i) entering the coordinates of a rectangle covering the area (ii) drawing the AOI into a map with a tool provided or (iii) uploading files containing geographical information such as shapefiles or KML files, created withGoogle Earth.

(2) Select the date or time span: Depending on the characteristics of the hazard, an exact date or time period must be chosen. For drought assessments, a long time series is needed, while flood data acquired near flood-peak are of most value.

Box 5: Acquiring EO data:
- Choose spatial extent
- Choose exact date or time period
- Choose sensor(s) / indices

(3) Select a sensor or index: Many data hubs provide a diverse range of different datasets, so you must choose the datasets, or the appropriate index/indices from your desired sensor(s) following the instructions under task 1 – Identification of appropriate EO data. Sometimes a combination of different sensors and indices can add value to the analysis (e.g. using optical as well as radar imagery for flood detection).

(4) Use a filter to remove data not meeting the quality you require: Optical images with a high percentage of cloud cover, for example, can be automatically excluded from the search.

Table 5-7 provided in Part II lists different types of EO data for hazard assessment. As there are many possible sensors, we provide 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.

Please find a list of different websites for data download in Part II. Document the main characteristics of selected remote sensing datafor hazard assessment in the report template.

3: Process EO data to detect hazard events, quantity, duration and f requency of hazard events and assess hazard severity

Many EO datasets provided for download contain pre-processed data, which we recommend using. The data are already corrected for atmospheric influences, and geometric or radiometric distortions.

If pre-processed EO datasets are not available, you must carry out the pre-processing. Atmospheric corrections reduce the uneven influence on spectral values due to water vapor, for example. Geometric corrections project the EOdata onto a plane (a constant base elevation) using a map projection and datum. Standard open source software, such as “R” or “GitHub”, has such processing modules.

Remote sensing data that has already been processed in the form of indices does not need any preprocessing (e.g., drought indices used for drought hazard assessment).

Document the data-pre-processing steps that are needed for your application.

4. Calculate hazard characteristics

In order to map hazard event characteristics, you will need to turn EO data into appropriate hazard indicators, such as flood extent or drought severity.

Translating satellite data into land cover information is a complex task, commonly using pixel- or object-based approaches. Spectral features are typically used to classify the individual pixels of the EO data into land cover geoinformation, such as water or flooded areas. Supervised and unsupervised methods are available in Open Source software such as “R”, Quantum GIS or “GitHub”.

To conduct the drought hazard assessment we suggest using the Vegetation Health Index (VHI), which has already been successfully used for drought detection in different regions worldwide. The index, which can be obtained free of charge from the Center for Satellite Applications and Research (STAR) , has been calculated on a time series of optical AVHRR data available since 1981. The drought hazard assessment should use weekly data covering at least 30 years. As each year will be processed individually, it will comprise a dataset containing 52 layers (one for each week of the year).

To conduct the drought hazard assessment, proceed with the following steps for each year:

(1) Determine the relevant weeks for the assessment: Depending on the aim of the drought assessment subset the yearly data. If agricultural droughts are being investigated for example, only the months relevant for agriculture should be taken into consideration. Information about these months can be found from seasonal calendars provided by institutions such as the Famine Early Warning System Network (FEWS NET) or the Food and Agriculture Organization of the United Nations (FAO). If livestock raising, including pastoralism, is included, the whole year needs to be considered.

(2) Subset the yearly dataset to the identified above relevant weeks. The resulting dataset will have as many layers as the number of weeks relevant for the assessment.

(3) Extract land use areas to be investigated depending on the aim of the drought assessment: If only agricultural droughts, or only droughts in pastures or rangeland are under investigation, areas predominantly covered by other land use types may be excluded. This step can also be performed at the end of the analysis, as the calculations are being carried out on a pixel basis.

(4) Create a drought mask for each week (= layer) of the dataset created above: To detect drought areas within each layer a VHI threshold of 35 and smaller should be used to create a binary mask in each layer. If a pixel value is higher than 35 the value 0 should be allocated to that pixel in a new dataset; if the value is equal or lower than 35, the value 1 should be allocated. This will result in a drought mask dataset with information in each layer of the spatial distribution of droughts during each week under consideration (1 = drought, 0 = no drought). This can be used to derive further information such as drought duration, intensity and severity.

(5) Calculate drought duration: Summing up the values of the drought mask layers created in (4) will result in a drought duration dataset for each year, indicating how often drought has affected a specific pixel during the growing season. With these datasets, you can create drought duration maps.

(6) Delineate drought area per year: Use the drought duration information calculated in (5) to extract areas affected by drought within a specific year. Allocate the value of 1 to all pixels in a new drought area dataset with a value of 2 and higher in the drought duration dataset (5) and a value of 0 to all other pixels. Using the threshold 2 instead of 1 is supposed to eliminate outliers. This will result in a binary mask of areas affected by drought within the growing season of a specific year.

(7) Calculate Drought Frequency: Use the yearly datasets created in (6) to calculate drought frequency. Summing up the binary datasets of each year will result in a dataset containing information about how often a single pixel was hit by a drought

within the time period under consideration. This information can be used as an indicator for drought hazard.

(8) Calculate Drought Intensity: Calculate the mean drought value for all drought weeks using the VHI within the time span under consideration and deduce this value from the threshold value of 35. The higher the resulting value is, the more intense the drought was.

(9) Calculate Drought Severity: Multiply the two values for drought duration and intensity: the higher the value, the more severe the drought. If the data range is large enough, you can establish severity classes for better visualization and understanding.
Document the calculated hazard characteristics in the report template.

5. Validate

It is crucial that you assess the accuracy of your classification result, as remote sensing techniques are not cadastral information. The systematic visual comparison between classification and satellite data is one approach as a reference truth is mostly absent. Typical measures for accuracy assessment are the error (or confusion) matrix with producer's and consumer's accuracy or the kappa statistics. In a confusion matrix, your classification results are compared to additional ground truth information. The strength of a confusion matrix is that it identifies the nature of the classification errors, as well as their quantities. The rows correspond to the ground truth map; the columns correspond to classes in the classification result. The diagonal elements in the matrix represent the number of correctly classified pixels. The off-diagonal elements represent the misclassified pixels. The Kappa statistic characterizes the degree of matching between reference data and classification. It describes the agreement found in the actual matrix and the chance agreement.

The remote sensing approach suggested in this handbook uses plant stress resulting in altered spectral signature of plants as a proxy for droughts. It does not directly measure the soil moisture deficiency responsible for agricultural droughts. Hence, finding an adequate ground truth dataset is very difficult, so that a validation of drought hazard information is not really possible. However, the plausibility of the results can be checked either by using the information contained in event databases or by comparing the results with other indices used to measure meteorological droughts. To set up the databases, please see Step 2.2 - Option 1. As a basis for comparison we suggest using the Standardized Precipitation Index (SPI), an internationally accepted index for measuring meteorological droughts. The results of a drought analysis based on the SPI and the results of the approach suggested here can be compared and checked, as it is very likely that meteorological droughts lead to drought-related vegetation stress and thus a change in the spectral characteristics of plants. Please note, that plant-stress can also be related to other factors such as plant diseases.

The other remote sensing approach suggested in this handbook is flood mapping. As ground truth data in flood events are not available, we suggest a visual comparison between satellite data and classification result. By using a random distribution of pixels, you can assess the accuracy with, for example, the confusion matrix.

Document the results of the accuracy assessment of your derived hazard maps in the report template.

6. Interpret and document resulting maps

Creating maps will help to visualize the spatial information of the calculated hazard characteristics and interpret your results. The following maps can be generated for every year under consideration:

- Drought Duration Map: Each pixel of the map will indicate the number of weeks it was hit by a drought during the growing season.
- Drought Area Map: This map shows the area that has been hit by a drought within the growing season of a specific year.
- Drought Intensity Map: Each pixel will depict the intensity of the drought that occurred during the growing season of a specific year. No value means that the region depicted by the pixel was not hit by any drought. The drought intensity ranges from 1 (very low intensity) up to 35 (very high intensity). Please not, that 35 is more of a theoretical value and values higher than 20 can already be interpreted as very high.

As a single map summing up the drought hazard information a drought frequency map can be generated. Each pixel of the map will indicate how often it was hit by a drought within the time period under consideration. This information will help establish the susceptibility of a certain region to droughts.

Please provide the resulting maps in the report template and document the results of your intepretation of drought location, duration, severity and frequency.

Step 3: Conducting the vulnerability assessment

To assess risk to natural hazard(s), it is important to understand why hazard impacts affect people, communities or ecosystems differently, as well as what resources people and communities have to cope with impacts. The concept of vulnerability provides a framework for analyzing socio-economic and environmental characteristics in relation to a certain hazard. Vulnerability is dynamic, multi-dimensional, and highly context-specific, which means that a vulnerability assessment for one region and hazard type cannot be applied to a different region and/or hazard type. The examples can be found in Part II.

Although vulnerability is defined in different ways in the literature (Part II), the key components of vulnerability that reappear in these definitions are susceptibility, coping and adaptive capacity. The research, which was conducted in the WASCAL program and provides the basis of this handbook, added exposure of social-ecological elements to hazard event impacts, and the lack of ecosystem robustness (please see Figure 3, Step 1). You may also refer to Kloos et al., 2015, for in-depth reading on the specific conceptual approaches to vulnerability and its sub-components.

Why is vulnerability assessment so important? Decision making for disaster risk management often relies only on hazard monitoring, but if hazards alone provide the basis of information, decision-makers will not understand the variety of real consequences that may be caused by hazard event impacts. This may lead to inappropriate actions, either a lack of response in the case of a low hazard severity but high vulnerability (for example, because of high exposure and lack of coping capacity), or a redundant response activity in the case of high hazard severity but very low vulnerability (e.g., because communities have efficient adaptive capabilities and thus low exposure).

Step 3.1 Guiding questions to pose for vulnerability assessment

The following questions are similar to those asked in the planning phase (Step 1). Here, however, you specifically answer these questions from the perspective of vulnerability per se.

Vulnerability TO WHAT?

You must first consider which hazard you are assessing vulnerability for. This handbook considers floods, flash floods, droughts or dry spells. Other natural hazards relevant in West Africa may be sea level rise, cyclones , bush fires, or epidemics, among others.

Vulnerability OF WHAT?

What is the unit of analysis? Does the vulnerability assessment focus only on either population, infrastructure, economy, or environment? Or will you take a systemic approach, such as a social-ecological system analysis as proposed in this handbook?

<u>Vulnerability assessment FOR WHAT PURPOSE?</u>

Who should be informed with the final result of the vulnerability assessment?

• Will the product be used for decision making in any specific phase of the various disaster management processes (e.g. mitigation, early warning, recovery, prevention, or disaster risk reduction)?
• Who will be the decision maker or end user of this assessment? A local stakeholder from a specific sector? A disaster manager? A spatial planner?
• Which spatial scale is considered by this assessment? Is the decision making process related to a local area (e.g. watershed) or for a whole country or even a larger region?

Most of these questions should have already been answered during the planning phase of the assessment.

Summarize the answer to the above questions for the specific assessment in the report template.

> **Box 6:**
> *In case of flooding, people and their livelihoods experience both direct and indirect impacts. Education is affected when roads are impassible, and travel to school is difficult or impossible. Health is affected when illnesses are triggered directly by the increase in mosquitoes, but also less directly from illnesses that develop in damp and damaged houses. In terms of livelihoods, the direct impacts of crop damage are augmented by demands on income to cover healthcare costs for illnesses triggered by the flood event or the poor housing conditions.*
>
> *Source: Joanna Pardoe – PhD thesis*

Step 3.2 Assessing vulnerability

Assessing vulnerability means that you assess and understand why some households, communities, agricultural fields, or socio-ecological systems (see "Vulnerability of WHAT" under 3.1) are affected differently by hazard impacts with similar severity levels.

Vulnerability assessment can be qualitative or quantitative. If vulnerability assessment is qualitative, it results mainly in narratives that document the vulnerability characteristics of the units or system of analysis facing certain hazard impacts . An example of such a narrative is documented in Box 6. The methodological approach to derive such a narrative, and extract relevant information for decision making from it, is documented in Option 1, below.

Option 2 explains a very specific approach based on a scenario analysis to assess the dynamic nature of vulnerability due to changing hazard conditions.

Option 3 describes a quantitative vulnerability assessment, for which you will need to derive indicators that clearly document the vulnerability components, and can be measured and quantified based on physical data.

Table 2 summarizes the three vulnerability assessment options. Detailed step-by-step descriptions of the methodological approaches and potential outcomes are documented for each option separately. If you have the professional expertise and resources to conduct all three options, they can complement each other and provide a holistic, comprehensive picture of vulnerability.

If you would like more information on different definitions of vulnerability, as well as conceptual framework please see Part II. The framework developed specifically for multi-hazard risk assessment in the West African Sudan Savannah region is illustrated and documented in Figure 10 (Part II). The framing of the assessment is an essential step to document the approach that will be followed for the vulnerability analysis.

Following Table 2, the individual options are described in more detail, with links to scientific technical background information, and relevant resources.

Table 2: Overview of three different options to follow for conducting a vulnerability assessment.

	Vulnerability assessment		
Option	**1. Understanding vulnerability based on narratives**	**2. Understanding dynamics of vulnerability based on scenario analysis**	**3. Quantifying vulnerability based on indicators**
Activities	1. Prepare semi-structured interviews 2. Select interviewees 3. Conduct interviews 4. Synthesize and document results of semi-structured interviews	1. Prepare scenarios 2. Prepare serious game to "play" the scenarios 3. Select the role playing participants and playing the game 4. Synthesize and document results of (scenario-based) game processes	1. Select a conceptual framework and review existing indicators related to the hazard(s) 2. Conduct technical workshops with different groups of experts 3. Elicit and rank indicators 4. Collect data to inform selected indicators 5. Compile and map vulnerability
Output	• Web of impacts • Vulnerability to single and multiple hazards	• Estimated loss and damage (crops, livestock, other livelihood resources) per scenario • Potential coping strategies of local population per scenario	• GIS maps with layers of vulnerability indicators • Maps of single components of vulnerability • Maps of compiled vulnerability
Professional expertise needed	• Interviewing and focus group skills • Some qualitative data analysis skills would be helpful • Basic computer skills • Knowledge of relevant local language	• Experience in participatory approaches • Some experience in serious games, or companion modelling • Knowledge of relevant local language • Some knowledge of game theory	• Interviewing and focus group skills • Knowledge of relevant local language • Some qualitative data analysis skills would be helpful • GIS and remote sensing expertise
Resources needed	• Preferably a computer and software to illustrate results; it is also possible to draw results on paper	• Game board and pieces • Statistics for livelihood resources in the study area	• Computer and GIS software

Step 3.2 – Option 1: Understanding vulnerability based on narratives

1. Prepare semi-structured interviews

The aim of this exercise is to understand people's vulnerability across a broad range of categories, to natural hazard event impacts, as well as their coping strategies due to floods and droughts. The full range of impacts and coping strategies have to be taken into account. People's retrospective view of the hazard events and their impacts illustrates their vulnerabilities based on real-life experiences of harm. The practitioner can also gain an understanding of how they have coped with the different crisis or disaster situations.

The semi-structured interview design should elicit data relevant to the purpose of the study and at the same time to not center on the perception of vulnerability and keep an exploratory character of the interview. The 'well-being' categories for enquiry make sure the interview covers all aspects of life in order to reveal what might be affected during a natural hazard event.

Wellbeing is based, theoretically, on the notion that society values more than simply economic success, and thus they should capture aspects of life beyond economic factors. The concept and categories of wellbeing also serve as a useful structure to ensure that interviews cover the full range of lifestyle factors. If you use this option in conjunction with Option 3, this categorization supports also the development of indicators. The proposed selection of well-being categories include:

(1) Livelihoods (2) Access to essential resources (e.g., land, water, fuel, construction materials) (3) Housing (4) Health (5) Education (6) Transportation (7) Social relations (8) Happiness (9) Politics and Governance (10) Technology (11) Beliefs and customs.

Adjustments to these categories can be made as necessary.

Experiences from previous vulnerability assessments based on narratives have shown that the categories most relevant to the communities where the vulnerability is being assessed emerge during initial conversations or focus groups. You can focus on these prioritized categories with more detailed questions during the interviews, however, also in order to ensure your assessment maintains a holistic nature, interview questions should cover every category.

Each individual interview should determine basic socio-economic information, such as

- the structure of the interviewee's household (number and ages of members)
- the interviewee's position in the household (e.g. male head, daughter)
- the interviewee's main livelihood and secondary income generating activities, as well as
  - o number and type of animals the interviewee owns and/or is responsible for
  - o the number and type of fields or plots he or she owns, is responsible for, and/or

has access to the types of crops he or she cultivates

• access to resources important for the household and livelihood(s), e.g., water sources, pastures, cooking fuel, construction materials, markets, schools.

Following these introductory questions, the interview contains two main sections: (1) analyzing the hazard event impacts, and (2) analyzing adaptation (management) and coping strategies for the hazard(s) based on real life experiences. For the first section, the interviewee will describe the hazard impacts and their effects. To guide this discussion, you should use the well-being categories that a wide range of impacts are covered. For example, you should ask:

• How did the flood/drought affect your livelihood?
• How did the flood/drought affect your housing?
• How did the flood/drought affect your children's education?

Questions should continue to ask about all relevant well-being categories.

Following the description of the impacts, you should ask interviewees first if there were any strategies they used to prepare for the hazard, then how they managed and responded to the specific impacts of the hazard event under study, and finally if there are new strategies that they have adopted to prepare in case the hazard comes again. These important questions will reveal and help you to understand damage from hazard event impacts, vulnerability to another similar hazard event and the coping and adaptation strategies used to reduce vulnerability to the hazard. The interview should cover the recovery process in detail to understand (1) to what, (2) how much, (3) how rapidly, and (4) how the individual and her/his household was able to recover, if at all. They can also reveal if and how the individual prepared before the hazard event, and is preparing for the next.

After developing your questionnaire, it must be translated into the local language of the study area. We recommend that your translator(s) has/have a good understanding of the questionnaire and of the objectives of the study. You should test the questionnaire in the relevant language with a few people similar to (but not among) those in your research communities to make sure that you ask understandable and appropriate questions, and that the questionnaire is not too long. For example, some questions may elicit redundant or unnecessary information and should be taken out.

Check the boxes of the well-being categories that are considered relevant for your study and elaborate questions in this context.

2. Select interviewees

WASCAL CRP WP5.1 began with an initial target of 10 interviews per village, which combined came to 100 interviews for each case study area. Though the researchers reached an understanding of people's vulnerabilities before all 100 samples had been collected, we recommend conducting approximately 10 interviews per village or

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community. You should select your interviewees first based on their experience with the hazards that you are studying (retrospective analysis of impacts), and secondly, consider the diversity of the community, making sure that you select a balanced number of women and men, from different ages, wealth statuses, ethnicities and livelihoods. If you have extensive knowledge of the community and individuals' experiences of different hazards, you may conduct stratified random sampling. You first divide the target population (people with experience) into smaller groups with similar attributes and characteristics (men, women, different ages, different wealth statuses, different ethnicities and livelihoods) and select your interviewees randomly from these groups.

Easier methods are purposive sampling (if you know the experts you need to interview) or snowball sampling, where one interviewee will inform you of other people you should interview. With this latter method, you again must keep in mind the diversity that your interviewee sample. The whole community, and not just one sector, should be well-represented. This requires some knowledge of the entire community, as elites may direct the interviewer only to their kind and either inadvertently or deliberately. These sampling methods may not be rigorous enough for statistics, but they are adequate for obtaining different narratives of peoples' experiences, strategies and coping mechanisms around hazard events, as long as the researcher selects individuals with consideration to the diversity in the community.

Summarize the selected interviewees with regard to their localoty, hazard addressed, number of interviews in the report template.

3. Conduct interviews

You must make sure that all interviews follow the same procedure in all villages or communities of each study area, as well as in each different study area. They should be guided by the underlying goals of your vulnerability assessment. In addition to noting all answers to interview questions, we also highly recommend that you document any additional information with regard to homes or livelihood assets (livestock, fields, gardens). Although you will probably not ask for very sensitive information (in which case you should always interview a person alone), it is usually better to interview people without those who can negatively influence the interviews. In a positive case, children may help a parent to remember information they have forgotten; in a negative case, a husband may start answering for his wife and not allow her to give her own information or point of view. If women hear the answers that their husbands have given, they may simply repeat the same answers.

4. Synthesize and document results of semi-structured interviews

Interview answers should be recorded in a notebook (or computer tablet, if possible and practical), and also by voice recorder. The recordings will serve to clarify the written notes, and, if resources are available be transcribed in part or in whole for

more detailed analysis. The transcribed results of interviews should be attached to the report form to complement the assignment.

The semi-structured interviews will provide a lot of new information to understand communities' vulnerabilities to the selected hazard(s). For example, the interviews will provide an excellent tool to reveal cascades of impacts, that is multiple impacts from one hazard event, and to delve deep into the recovery process. All this information needs to be synthesized and analyzed to some extent in a quantitative manner in order to draw some useful conclusions.

Hazard Event Impact Table

First, we suggest that you summarize impacts described by interviewees, and aggregate the results by hazard and by well-being category in the provided table. Complement the table as you see fit. Note how often each impact was mentioned by interviewees.

If multiple hazards were selected for this assessment, you should structure the results separately per hazard and aggregate the total of impacts in an additional column. This will help you understand whether certain impacts are very hazard specific or a more general issue for the respective region. To gain a more detailed and holistic picture of vulnerability in the region, note which group of people in your range of diversity mentioned or were more concerned with which impacts.

Document the resulting impacts per category of well-being and the description of experienced impacts per hazard in the provided tasks of the report template.

Web of Impacts

Following the quantitative analysis to discover the number and frequency of reported impacts, as well as the different effects for different groups in the community, a "web of impacts" will help you to understand the cascading effects of the impacts. First link immediate damage, harm or impacts mentioned in the answers to your semi-structured interviews to the hazard event that caused them. Link them to each other, if they are related. Then link subsequent impacts to the primary impacts – to more than one if appropriate, and to each other if they affect one another. If multiple hazard events happen in close succession, you can link the hazard events and the impacts to show the relationships between all of them. The resulting web of impacts will provide an in-depth, graphic illustration, to help understand vulnerability characteristics for the selected hazard(s)in your study area. Figure 5 provides an example of web of impacts that document the interrelation, cascading effects and feedback loops of impacts following floods and/or droughts.

Draw such a web of impacts for your study based on information retrieved from the semi-structured interviews and describe the relations in the web of impacts.

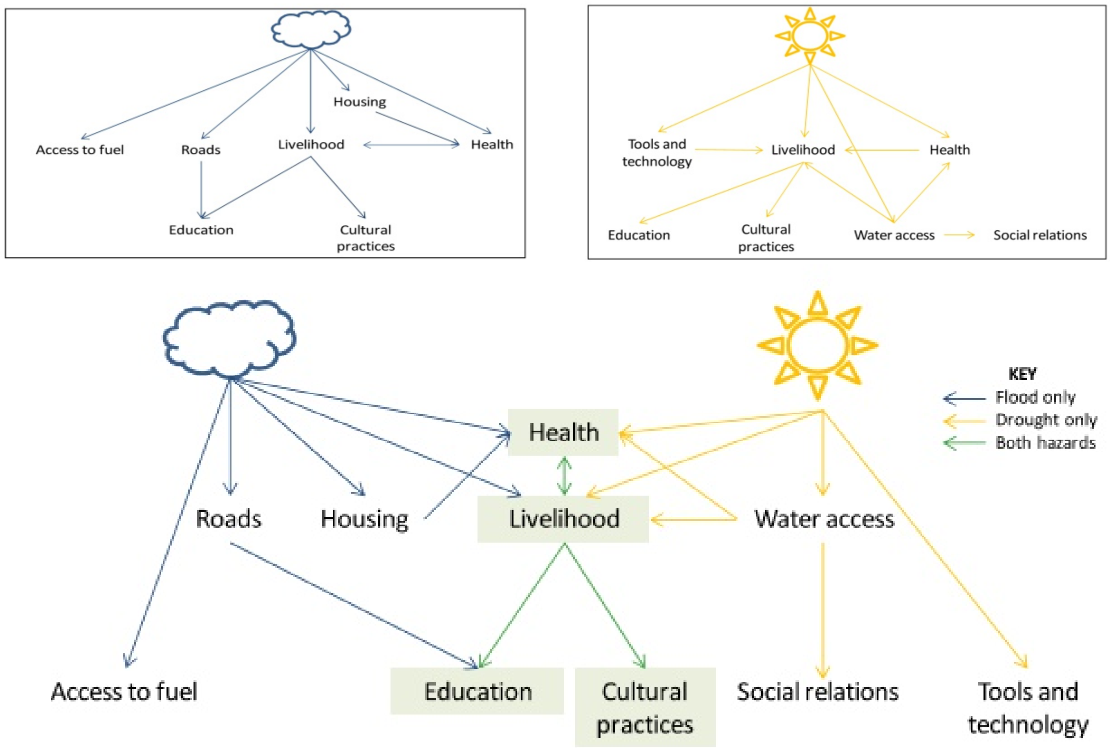

Figure 5: Examples of web of impacts caused by floods (top left) and droughts (top right). The lower image illustrates a synthesized web of impacts caused by floods and droughts. The web of impact is a means to document and illustrate multiplier and cascading effects of impacts due to natural hazard(s). (Source: Joanna Pardoe, UNU-EHS)

Table of Coping and Adaptation Strategies

To document coping and adaptation strategies, we recommend that you clearly discriminate between short term coping strategies that respond to the experienced hazard impact, and longer term adaptation (or management) strategies that aim at general changes and permanent adjustments taken either in anticipation of or in reaction to hazard event impacts. List the coping and adaptation strategies mentioned in your semi-structured interviews in the report form. Note which group mentioned them, and how often. You might also note whether the interviewee perceived the strategy as useful and/or beneficial or harmful, but used because there was no alternative.

Table 3 provides examples of coping and adaptation strategies gained in WASCAL’s CRP WP5.1 study on vulnerability to floods and droughts. The strategies listed here provide information how individuals and their community attempt to recover from a hazard event through coping strategies, and trying to reduce their vulnerability through adaptation strategies. This analysis will help authorities see which coping and adaptive strategies show the most promise in which communities and for which groups of people, which need to be adjusted, and whether new strategies might be proposed. A strategy that has worked well for women in one community might be proposed to women in another community, and adapted if necessary. Some coping strategies may actually cause more harm to households, and authorities may be able to propose and work toward alternatives.

List the coping and adaptation strategies mentioned in your semi-structured interviews in the report form. Note which group mentioned them, and how often. You might also note whether the interviewee perceived the strategy as useful and/or beneficial or harmful, but used because there was no alternative.

Document the results of your semi-structureed interviews with regard to coping and adaptation strategies in the provided table in the report template.

Table 3: Examples of some coping and adaptation strategies for floods and droughts at the local level in West Africa.

Coping strategies	Adaptation strategies
Seasonal wage labor migration Generate additional sources of income e.g. small-scale trading (selling small items, processing of goods)	
• Selling livestock • Taking out loans • Reducing frequency of meals • Interrupting children's school attendance • Access to shelter of neighborhoods/relatives during flooding • Use of mosquito nets during a flood event • Access to supplementary water resources for livestock • Governmental disaster response activities	• Changes in the timing of sowing seeds • Relocation of farms and houses • Re-building collapsed buildings so that they are more resilient • Using improved seeds • Alternative occupation training • Permanent migration

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

Asking people directly in an interview has been shown to provide little information for understanding the dynamics of vulnerability. WASCAL CRP WP5.1 successfully tested a game-based approach as a methodological tool to understand in a dynamic way how people might be affected by and respond to hazard event challenges. This "serious game" is a simplified model of key features in the study area exposed to simulated hazards.

In this exercise, the aim is to understand vulnerability dynamics based on people's perceptions of impacts when confronted with a hazard event, and their possible coping strategies. Here, the perspective changes from the retrospective view investigated in Option 1, to a prospective view where impacts and coping strategies are anticipated. Climate change projections indicate more frequent flood and drought events, which might influence vulnerability and thus coping and adaptation strategies.

The game developed for this handbook and the scenarios illustrated in Figure 6 are based on the research experience of the WASCAL CRP WP5.1 with farming communities in the Sudan Savannah agro-ecological zone. With some knowledge of your research communities, and modification of game pieces and board, it can be adapted for other livelihoods and agro-ecological zones.

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1. Prepare scenarios

This Option 2 requires some detailed knowledge of the research communities and study area: what livelihoods they engage in, what natural hazards they face, and possible impacts of hazard events. Prior to beginning any game activity, you should conduct short focus group or key informant interviews to better understand the communities' experiences. Of course, if you conduct this Option 2 in conjunction with Option 1, the interviews you conducted for Option 1 will serve for this one as well. The focus groups or interviews should tell you if the communities meet the criteria you need for the study (that is, experience with the hazard events you are researching). Then the scenarios must be designed so that they reflect both the purpose of the study and the specific situation of the selected study area and experiences of the communities (livelihoods, crops, livestock, resources, etc.).

The first task of preparing the scenario is to determine the most relevant crops and/or livestock for the research communities. The most common crops in the three different study areas investigated during the WASCAL CRP WP5.1 were maize, rice, sorghum and groundnut, with millet and cotton were considered as additional important crops for individual sites. The next step is to develop scenarios based on hazards that may occur in the study area.

In the WASCAL CRP WP5.1 study, vulnerability dynamics were investigated using two different scenarios. In Scenario 1, after "planting crops", a dry spell of two weeks occurs 30 days after planting. Following this, a flood event hits the same crops 30 days later (60 days after planting). In Scenario 2, the sequence of hazard events is reversed. Thirty days after planting, the crops are flooded, and a dry spell follows 60 days after planting. These scenarios aim to imagine real situations in order to discuss potential impacts and coping strategies (see Figure 6). As basis for developing reasonable scenarios you need to document the most important capitals in the region that influence vulnerability. Examples are the main crops or livestock produced. Following this you need to document the narratives of the scenarios that provide the basis for this serious game-based approach in the report template.

2. Prepare serious game to "play" the scenarios

The key components that you will need for the game are essentially some sort of surface to represent the landscape, and different sorts of pieces to represent the different types of crops, livestock, buildings, or other elements that may be exposed in a hazard event. You will also need decks or "event" cards that detail the different hazard events that you are studying. A production calendar will help determine the timing of your game. A die is used to add an element of uncertainty to the risk and the amount of loss due to a hazard event. You will also need objects to symbolize crop harvests (sacks) and production inputs and other resources.

Your choice of what to represent with your game surface and pieces will depend on the

purpose of your study, and the specific situation of your research community and study area. Depending on your resources and experience with participatory methods, you might use a wooden board, heavy cloth, or the ground, and wooden blocks, plastic beads, pieces from board games, or natural objects such as rocks and sticks. To overcome difficulties with illiteracy, no text should be used, rather the game pieces should be as different as the different elements of your scenario. You should use different objects, colors and shapes to help the players of your serious game distinguish between crops and livestock, for example, and among different crops (e.g., maize, millet, rice) and livestock (e.g., cattle, sheep, poultry). If your game surface represents more than just fields or pastures, the landscape elements (roads, rivers, etc.) should be easily identifiable. The game board should also not be too complex and difficult to understand, though.

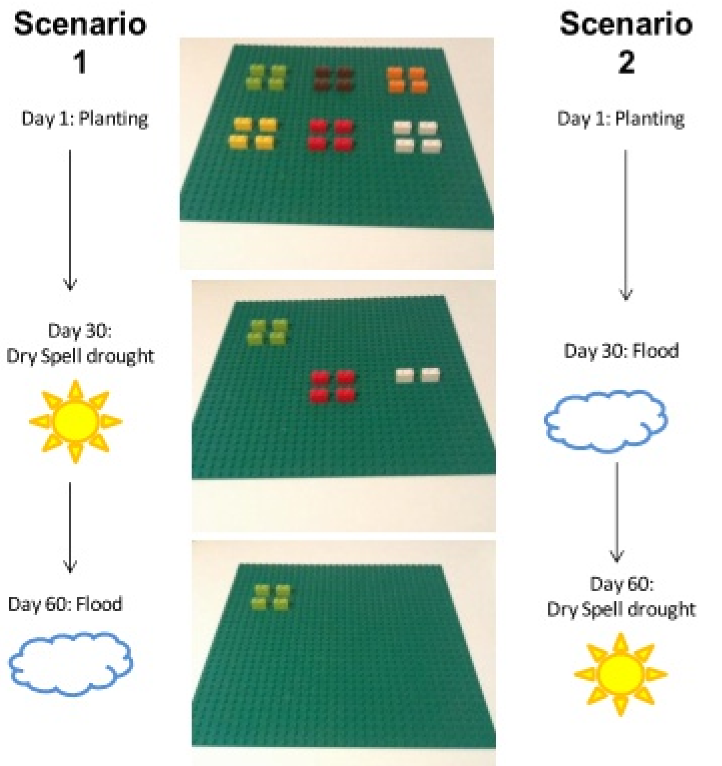

Figure 6: Illustration of a serious game with two scenarios developed for rural communities in the sub-Saharan Savanna zone. Source: Joanna Pardoe

The 'event' cards should be 'weighted' by the numbers of each type of card in the decks, to represent the chance (real or slightly higher than normal) of the hazard event. Using different types of cards in the same game will reflect multiple hazard situations, or the occurrence of different types of animal diseases. The production calendar should at least represent the rainy and dry seasons, but may also take into consideration planting and harvesting times for cultivation, or breeding and birthing periods for livestock raising, for example. Event cards may be divided by the seasons, for instance floods and dry spells will happen in the rainy season. Livestock diseases may also be seasonal.

In the WASCAL CRP WP5.1 game, the researcher used green Lego boards to represent fields, and differently colored Lego board bricks to represent different crops (see Figure 7). Differently colored tacks on cork boards represented different types of livestock, as well as house buildings, on cork boards that represented the house compounds. 'Event' cards represented climatic hazard events (floods, droughts, normal conditions), occurring in the rainy season, and livestock diseases occurring during the dry season. The production calendar, drawn as a pie chart on paper, had four months for the rainy

season, six months for the dry season, and one month each for planting and harvesting at the beginnings of the rainy season and dry season, respectively. The game has been designed to be rather simple, but you may increase the number of players (five or six at most), and make the components of the game more complex and realistic (numbers of fields planted, crops grown, and livestock raised; resources available; harvest amounts and livestock obtained at the end of the season; product marketing) as your skill with the game improves. You might also diversify your hazard event cards to reflect other hazards, such as year-long droughts, intense precipitation, or cyclones. The game should always reflect the realities of the community and your goal of obtaining information on the impacts of hazard events, coping strategies, and adaptation strategies.

Flood and drought cards represented an average of one flood and one dry spell per year, which was more frequent than normal, at the time in the Sudan Savannah study area. Livestock disease cards were also weighted to an average of one disease per year, but following information from interviews further weighting was applied so that pig diseases were more common, followed by chicken diseases, goat and then sheep diseases.

A more detailed description of the assets used for the example of the game conducted during the WASCAL CRP WP 5.1 study, the details of the rules and regulations and required input information is provided in Part II. You now need to document the elements used in your serious game approach as well as the rules and regulations used here in the report template.

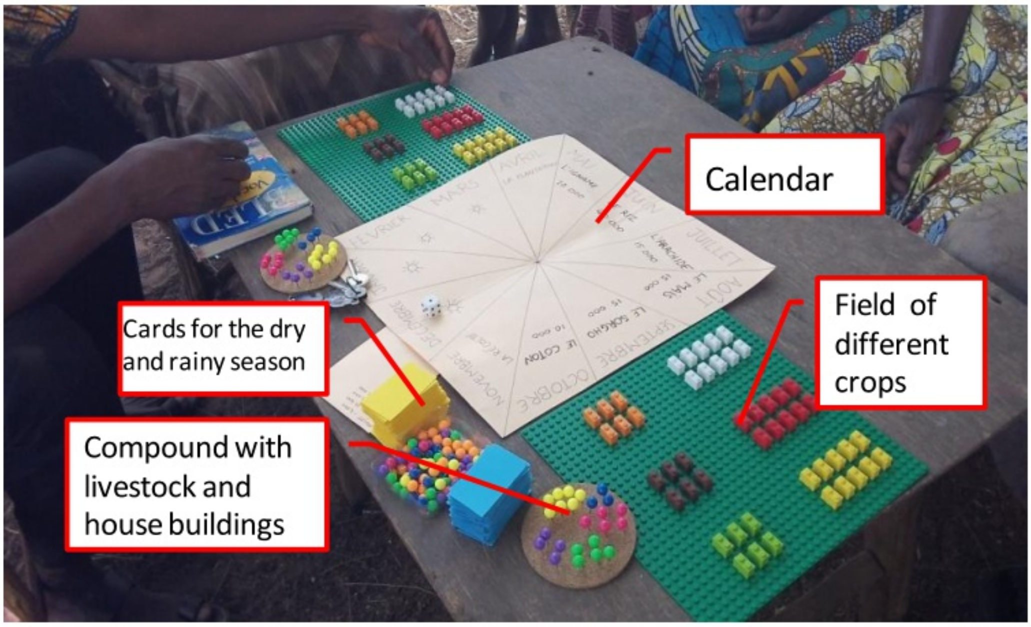

Figure 7: Annotated set up of game.
Source: Joanna Pardoe

3. Select the role play participants and play the game

The game is played with two players who each have an advisory audience with whom they can discuss their decisions during the game. The selection of the role play participants should be conducted based on criteria that are relevant for the purpose of the assessment, e.g. people that have been previously affected by hazards, people that are involved in agriculture, etc. As part of the selection process we recommend to document in the report template questions to be asked in the selected community to ensure that seleted role play participants fulfill the prerequisites.

After selecting role play participants, you must give detailed explanation of the different game components (board, playing objects, cards, calendar, etc.) and how the game functions. The players may feel as if they are in friendly competition with each other, each trying to obtain a better production than his/her opponent. The game should be non-confrontational, though, and the two players are allowed to support or advise each other. As the die roll gives each player different circumstances, they may want to support one another in difficult circumstances or to sympathize with their 'opponent' when they are unlucky with the dice. Such a cooperative atmosphere should be encouraged. The members of the audience should advise both players, rather than allying with only one player. Everyone should recognize that the game's objective is to defeat climate variability and risk rather than each other.

The 'event' cards are shuffled to create a random pattern of climatic conditions or livestock diseases. Then players play through each month around the calendar, drawing cards for hazard events and livestock diseases within their respective seasons. At the end of the rainy season, players are also given their "harvests" and more livestock depending on the quality of the season. This will enable players to work towards growing and increasing their assets in good years. "Harvests" are a 'sack' of produce for each crop that was not destroyed in the preceding season by drought or flood. New livestock should reflect the number of young born and surviving at the end of the season. Players are permitted one opportunity to trade their assets at the end of the rainy season.

As players move through the calendar and pick cards, each rolls the die when a card representing a hazard event is chosen to determine degree of losses from the event impact for the crop or crops that are susceptible in that month. A 1 represents no losses; 2, a 25% loss; 3 and 4 both representing 50% loss; and 5, a 75% loss. A6 results in the entire field of that crop being lost. It is important to provide variations in losses, including none and 100% to reflect the reality of farmer's experiences. A die roll may also determine livestock losses due to flood or drought, if this is appropriate to the circumstances.

When a flood card is chosen, the die roll will also determine the number of rooms in compound or homestead that would 'collapse'. The number of rooms in each player's

“compound” should reflect how the community builds their houses, but it should also be compatible with the six different sides (number of dots) on the die. Simulate this important impact of flood events will help you understand how people cope with the loss of their rooms or building, and whether assets (e.g., animals or crops) are sold to pay for such damage. During the game the players must rebuild in the dry season, so that you can observe which animals or crops are sold to pay for reconstruction. You should also note any objections to rebuilding.

Players should be encouraged to explain and justify their decisions throughout the game activity, and you should note why they make the decisions they do. At times, the group observers may disagree or suggest alternative strategies, highlighting the range of approaches to decision-making and trade offs. The discussions and different opinions of this group activity shows the diversity of approaches a community has to deal with the challenges of hazard events. Another advantage of the advisory group is that people can join in at any point in the game. If villagers happen upon the activity as it is in progress, they are welcome to add their comments and thoughts. You should facilitate a friendly and open atmosphere to encourage discussion about these difficult subjects. In this respect the game is an excellent tool, providing a novel experience that takes all the participants away from the stock answers they might give in a focus group or an interview.

4. Synthesize and document results of (scenario-based) game processes

During the game, we highly recommend to document every single step of the game procedure in the provided pro-forma sheet (see Pardoe, 2016, p.229). The game activities, including all steps, cards, die values, decisions and alternative ideas were recorded and comprehensively documented in the provided pro-forma sheet ("Resources"). In a next step, you need to extract and summarize the most essential information from this activity. Document the anticipated coping and adapatation strategies proposed by the individual players of the game for the respective scenarios in the report template.

Step 3.2 – Option 3: Quantifying vulnerability based on indicators

In contrast to the qualitative approaches of vulnerability assessment as represented by Options 1 and 2, Option 3 aims to assess and quantify vulnerability based on indicators, which you will measure and quantify using geospatial data.

1. Select a conceptual f ramework and review existing indicators related to the hazard(s)

The first step in developing a set of indicators for vulnerability (and risk) assessment is the development or selection of an appropriate conceptual framework. This framework must be comprehensive and well-adapted to your research area, so that it clearly establishes the relationships, interactions and feedback mechanisms that exist within the system (e.g., Social-Ecological System - SES) you are studying.

This handbook provides a conceptual framework that you can use to categorize the various dimensions of vulnerability in your research area. The framework considers how vulnerability is part of the complex SES. The framework's major components – Exposure, Susceptibility, and Capacities – involve both the social and ecological subsystems. Capacities include both coping and adaptive capacities in the social subsystem, and ecosystem robustness in the ecological subsystem. The framework will give you a template to operationalize and assess vulnerability within the boundaries of your research area. Please see more information on SES and the explanation of the conceptual framework used in this study in part II and in Kloos et al., 2015.

The initial step of the quantitative vulnerability assessment is a review of existing indicators that are related to the hazard(s) you have selected to study. This can be done in a very comprehensive manner by reviewing the scientific and non-scientific literature using most relevant keywords and online databases. However, in this handbook, you can also directly refer to a 'library' of indicators that WASCAL's CRP WP5.1 developed through comprehensive participatory research. You will also develop your own list through the next steps in this Handbook. If you have the resources, you should conduct a specific literature review with focus on the vulnerability to your selected hazard(s) in your research area. From your reading, you should develop a preliminary list detailing most commonly used vulnerability indicators.

2. Conduct technical workshops with diff erent groups of experts

Next you should hold a participatory workshop of local technical experts in your research area. They will list indicators based on their own experience, validate the indicators you have found in the literature, and rank all the listed indicators by importance. You should choose your experts using snowball sampling, meaning that you will ask local experts whom you know to recommend institutions and other experts involved in risk management and prevention with regard to the selected hazard(s), or support communities to reduce their vulnerabilities. All identified experts should be asked to indicate which of the relevant technical areas they have expertise

and competences in. WASCAL CRP WP5.1 found that the most relevant technical areas for the case of drought and flood risk in rural areas of Sudan Savannah agro-ecological zone were: (1) Agriculture, (2) Socio-economic and health matters, (3) Disaster management/meteorology, and (4) Environment.

Document the expert/ institutions you plan to involve in the participartory process of driving vulnerability indicators in the report template.

3. Elicitation and ranking of indicators

For this workshop, you will need to prepare a semi-structured questionnaire with questions about indicators for the different components of vulnerability. For instance, those in the agriculture group should discuss aspects of vulnerability linked to agricultural activities, such as how farms might be exposed to the selected hazard(s), how droughts and floods might affect the agricultural system, and the different elements of farmers' coping and adaptation capacities for floods and droughts. Those in the disaster management/meteorology group should discuss indicators of disaster preparedness, risk governance, impacts of disasters on human systems and the local economy. Those in the environment group should discuss questions on the state of the environmental systems, ecological and soil properties, water systems etc. The socio-economic and health group should focus on factors and conditions that expose people and make them susceptible to flood and drought impacts, and those that contribute to their coping and adaptive capacities, such as wealth levels, housing conditions, food availability, household dependencies and labor availability, social networks, and institutional support. The result of this participatory procedure is to understand key characteristics that drive vulnerability in the local setting and express this relation by indicators. Please see the indicator library as a reference, which resulted from the WASCAL CRP WP5.1 activity (in "Resources" folder). In addition, a template of questionnaires developed for this indicator development is provided in "Resources" folder. We strongly recommend that you revise and adjust these questionnaires to meet the purpose of your study.

Using semi-structured questionnaires during this workshop will allow the participants to actively discuss and debate among themselves as they develop the vulnerability indicators particularly relevant to their area. You should give each group a list of the indicators you derived from the literature and during the workshop (we recommend to use the existing indicator library as additional basis for discussion), so that they can determine their relevance for the present study. Each participant should be asked to determine the relevance of the given indicators for each vulnerability sub-component by choosing from three options: highly relevant, moderately relevant, and irrelevant. This expert-based ranking of indicators within each vulnerability sub-component will later be applied to the quantitative weighting of each indicator. In the end, all the indicators should be presented in order from most to least important in terms of defining the exposure, susceptibility and capacities of the SES in the area.

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Please note down the key questions/ topics to be addressed by the technical groups in the workshop as basis for designing the questionnaire.

4. Collect data to inform selected indicators

When you have your list of relevant vulnerability indicators for your selected hazard(s), the next step to quantify vulnerability is to test them with real data and measurements. Different data sources will be useful for different indicators. In general, you will obtain useful data from statistics, from remote sensing, or through specifically designed surveys. The indicator library in "Resources" folder provides for each indicator, along with its detailed description, a useful data source.

You will also find in "Resources" folder a standardized questionnaire, which the WASCAL CRP WP 5.1 used to collect fine scale household-based data for quantifying the vulnerability indicators listed in the indicator library.

The selection of communities for your survey should use information from local authorities about communities frequently affected by floods and droughts, number of people affected, population as well as relief items provided by the local authorities. Within each community, households should be divided into two groups, households that have been more affected by hazards and households that have been less affected. Based on this you can conduct a stratified random sampling and select households from each group. However, we recommend to have slightly more samples from the households that refer to the "more affected" group.

In addition to household surveys, data on processes and impacts of hazard events, especially multi-hazards, can be obtained from focus group discussions.

Note: You should not do a "household survey", interviewing only the "head of household" and expect that this will give you the diversity that you need for your research. If "households" are a unit of analysis, then all adults in the household with experience of the hazard(s) should be interviewed.

5. Compiling and mapping vulnerability

Once you have obtained your data, you must take several analytical steps to relate the indicators to your data in order to quantify vulnerability. After you have retrieved data values for all your indicators, the next step is to perform exploratory data analysis. To do this you must describe the value range of each indicator by its minimum, range, mean, maximum and standard deviation. At this stage, you can remove any indicators if you lack data for them or if they are too similar to others in the data set. Details on the technical procedure of calculating descriptive statistics is documented in Part II.

As a next step, a bivariate correlation matrix should be constructed to understand the strength and direction of the linear relationships between the indicators, especially between those indicators in the same component of the framework (e.g. susceptibility

of the social system). An example of how a bivariate correlation matrix is calculated is documented in Part II. For indicators with absolute metric variables, it is recommended to use the Pearson correlation coefficient for this bivariate analysis, while for indicators with ordinal variables the Spearman correlation coefficient is an appropriate estimate. As rule of thumb, all relationships with a coefficient above a threshold value of r=0.65 need to be carefully scrutinized. In case of high values of collinearity between two indicators, one of them needs to be removed. The decision can be driven by keeping the indicator for which availability and quality of data is superior. If varying degrees of significant correlations are found among indicators that belong to different components of vulnerability, they are deemed to represent different causes and aspects of vulnerability and thus those relationships can be neglected.

Indicators have to be normalized to have identical ranges (between 0 and 1). These normalized values serve as Level 2 inputs for the R script which generates graphic and tabular risk profiles (see Step 4.3 Generation of risk profiles). During the participatory process of deriving vulnerability indicators, the indicators should have also been prioritized or weighted by the stakeholders. This information needs to be converted into values of weights between 0 and 100%. A detailed description of statistical procedures to quantify the weights is documented in Part II and described in Asare-Kyei et al., 2017. However, for practical reasons it is recommended to allocate the weights proportionally and reach the 100% within and between the (sub-)components of vulnerability. An overview of indicators used for each component of vulnerability and the specific weighting of each indicator and the sub-components is illustrated in Figure 8.

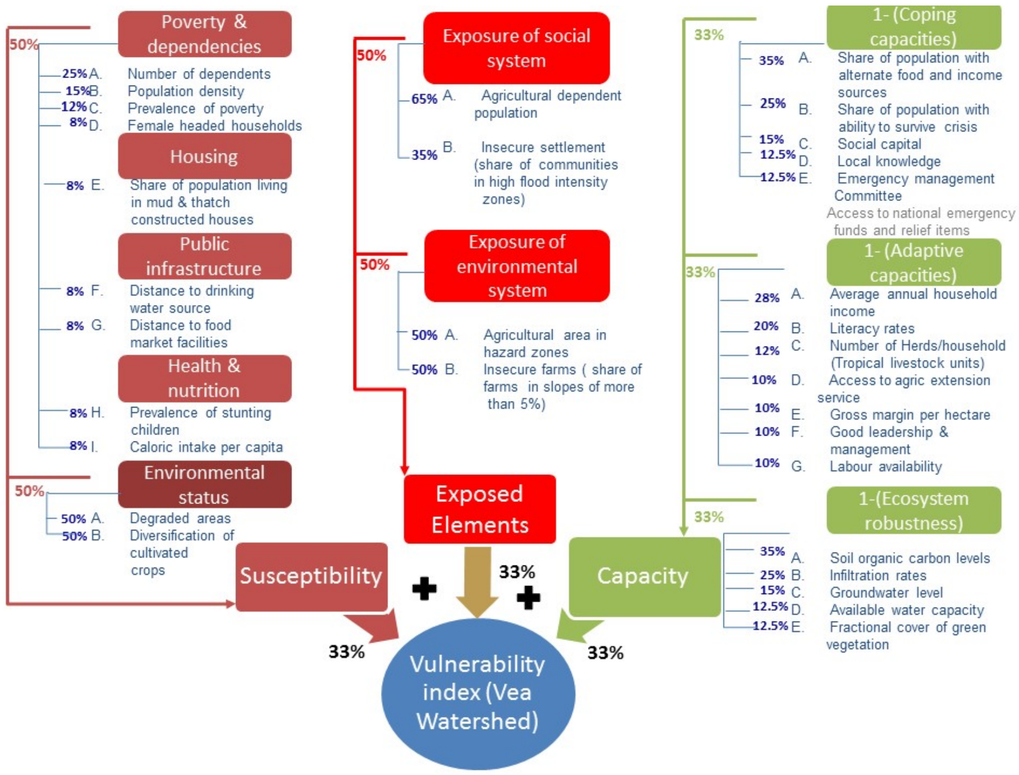


Figure 8: Development of a vulnerability index for the example of the Vea watershed in northern Ghana
Source: Asare-Kyei et al., 2017

The normalized and weighted indicators need to be summed up to derive the composite vulnerability index by applying the linear aggregation method. This approach is basically the summation of weighted and normalized individual indicators and is documented by the below equation:

$\mathbf{V}_{SES} = \mathbf{EE}_{SES} + \mathbf{S}_{SES} + (1-\mathbf{C}_{SES})$,

where $\mathbf{V}_{SES}$ stands for vulnerability of the SES, $\mathbf{EE}_{SES}$ stands for exposed elements of the SES, $\mathbf{S}_{SES}$ stands for susceptibility of the SES, and $\mathbf{C}_{SES}$ stands for capacities of the SES.

This additive aggregation function works only if the individual indicators are mutually independent. This implies that the function allows the assessment of the marginal contribution of each indicator separately.

The aggregation of the overall vulnerability index is a three-tiered process: It gets started with the aggregation of each sub-component (e.g. susceptibility of the social system), known as Level 1 in the risk profile generation process. Following this, an indicator for each component (known as Level 0) is aggregated (e.g. susceptibility) based on these sub-component indicators. Finally, the overall vulnerability index is estimated by combining the three indices describing exposure, susceptibility and (lack of) capacity. Equal weights are applied to each of the three indices.

These calculations – of weighting and aggregation – are performed automatically when using the normalized indicator values in the R script for risk profile generation (see Step 4.3.3). If you prefer, or if you do not have hazard data, you can use the R script for risk profile generation to create vulnerability profiles instead – to do so, simply leave out hazard as a component, and be aware that without hazard data, it becomes a vulnerability profile instead of a risk profile.

The resulting values can then be linked to the spatial units and imported into a Geographical Information System (GIS), where maps can be produced and illustrate the results of the vulnerability (or risk) assessment in a spatially explicit manner. Maps of exposure, susceptibility, lack of capacity and overall vulnerability should be copied into the report template.

Step 4: How to measure risk?

The overall risk to a natural hazard is composed of the two key components of information: the hazard (Step 2) and the vulnerability (Step 3). If both these elements have been assessed, the compilation of risk simply consists of the multiplication of both elements.

Step 4.1 Compiling risk f rom hazard and vulnerability measures

From the hazard assessment (Step 2 - Option 3) and the vulnerability assessment (Step 3 - Option 3), you should receive quantitative and spatially explicit information of hazard and vulnerability. This information is well suited to calculate the overall risk in a quantitative manner and develop risk maps and risk profiles from this data. The formula for compiling risk is given in below equation and illustrated in Figure 3 (see Step 1).

$$\mathbf{R}_{SES} = \mathbf{V}_{SES} \times \mathbf{H}_{M}$$

where $\mathbf{R}_{SES}$ stands for risk faced by the SES, $\mathbf{V}_{SES}$ stands for vulnerability of the SES, and $\mathbf{H}_{M}$ represents the characteristics of (multiple) hazard(s) (e.g. the intensity and frequency of droughts and floods).

The quantified $\mathbf{H}_{M}$ in the above equation delineates in a spatially explicit way the occurrence of floods and droughts and provides a measure of its intensity and probability of occurrence. The exposure of the SES to the two hazards of floods and droughts ($\mathbf{H}_{M}$) is a component of vulnerability as degrees of exposure of the critical elements (people, farmlands, protected area etc.) and the indicators of susceptibility and capacities. An MS Excel-based template in the "Resources" folder (filename: "calculating_risk_index_template.xls") is provided as basis for compiling the risk index in a guided way. If the overall risk is calculated for each spatial unit of your assessment, these values can be linked to the geospatial data and similar to the vulnerability maps displayed using GIS. The resulting risk map can be exported as image file.

Note in the report template the name and location of the MS Excel file with the calculated risk index. Export the map from the GIS and paste it in the report template.

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

An important step of risk assessment is to understand the uncertainties of the assessment and test the robustness and the quality of the quantified composite indicators. The estimated or modelled risk should provide sound information relating to the potential impacts of the hazards on the studied communities.

A technique to validate the underlying model and assumptions used to develop the community risk is based on real historical impact data collected from at risk

populations (see Step 2 Option 2). The so-called Community Impact Score (CIS) measures the cumulative impact of multiple hazard events over a period of five years. During field work as described under Steps 2 and 3, households are asked to recount the impact they have suffered over a defined period of time (e.g. last five years) as a result of the event of any natural hazard(s) (e.g. droughts, floods or multiple hazard events). The impact assessment should capture data on the following key variables:

(1) Population affected by the hazard(s) (%) by community cluster.
(2) Population affected by multiple hazards in the same year (%) by community cluster.
(3) Average area of cropland affected per community (ha).
(4) Average number of livestock affected/killed by hazards.
(5) Number of people killed by hazard(s) (human loss).
(6) Number of housing units destroyed or partially damaged by hazard(s).
(7) Economic value of properties (houses, personal effects etc.) destroyed by hazard(s).

To develop the CIS, these impact variables need to be standardized to make any combination meaningful. It is recommended to apply the linear interpolation method to standardize the impact variables. This procedure is documented by the below equation and results in standardized impact values on a scale of 1 to 4, with one being the lowest impact level and 4 for the categories with the highest impact levels. This procedure first involves the determination of minimum and maximum impact levels and then calculating the slope and intercepts of the impact level for each variable. The minimum and maximum values are used as the known variables in the horizontal axis, whilst the scale range of 1 to 4 is used as the known variable in the vertical axis in the estimation of the slope and intercept. The resulting slope and intercept values of the respective variables are then applied to each impact variable value using the equation below:

$$\mathbf{IV_{ST} = Integer\ ([slope\ x\ IV] + int + 0.5)}$$

where IV is the impact variable, IV_{ST} is the standardized impact variable and “int” is the intercept. The derived CIS needs to be scaled between 0 and 1 to correspond to the multi-risk index. There are several statistical model validation tools that can be used to assess how well the risk model approximates actual disaster impacts. The most relevant models are the Root Mean Square Error (RMSE) and the Coefficient of Determination (R^2) (explanation in Part II).

Document the variables that were used to calculate the CIS in the report template and note the formula used to calculate this index. In addition, we recommend analyzing the RMSE and R^2 to evaluate the quantitative risk assessment.

Step 4.3 Generation of risk profiles

This section contains instructions on how to create graphic and tabular risk profiles

from your quantitative hazard and vulnerability assessment data, using the workflow of indicator value transformation specified in the vulnerability assessment (see Step 3.2 – Option 3: Quantifying vulnerability based on indicators), by running a prewritten script in the statistical computing and visualization software R. This step does not calculate an overall risk score that multiplies hazard and vulnerability; instead, it focuses on displaying the relative contributions of the hazard and vulnerability components and subcomponents to the overall risk for a given administrative unit or community.

The results of the risk assessment in Step 4.2 can be displayed in maps using GIS, where each spatial unit represents a specific estimate of risk (see Figure 9). However, in most cases the prioritization of communities with highest risk is not sufficient; rather, detailed information about the most relevant characteristics and criteria that shape vulnerability and risk in the respective communities is necessary for targeted planning. This can be achieved by deriving risk profiles from the underlying quantitative risk assessment (see Figure 9). In the following documentation, the step-by-step approach to derive the risk profiles is documented. The R script to develop these risk profiles is provided in the "Resources" folder of this handbook ("risk_profiles_template.R").

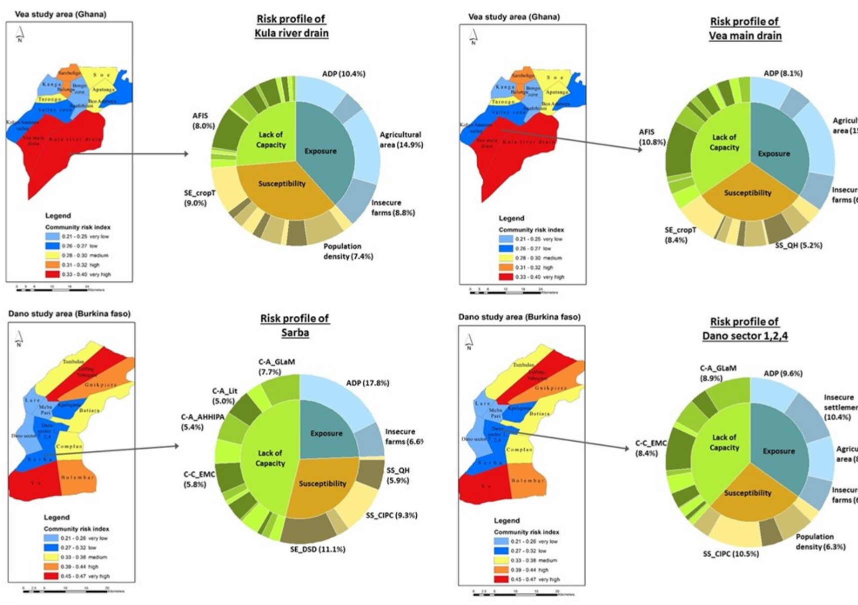


Figure 9: Risk maps and risk profiles of selected study areas in the WASCAL focal research sites. Source: Asare-Kyei et al., 2017

1. Installing R

You will be installing R, a free, open source software environment for statistical computing and graphics that uses its own programming script. The steps outlined in this document will enable you to generate graphics of risk profiles without the need to write or edit any programming scripts, except for basic inputs of file names and folder locations.

Navigate to the R Project website: *https://www.r-project.org/*

Once there, click on CRAN under "Download" in the upper righthand corner. Note: CRAN stands for "Comprehensive R Archive Network"; each CRAN mirror is identical and offers a download of the latest version of R - this is only done to reduce network load. Simply choose the website that is closest to your geographical location.

If you are using Windows: click on "Download R for Windows," then click on "base" (or "install R for the first time"), then on "Download R 3.3.2 for Windows" (note: version number may update and thus be different, but it will be at the top of the page). Run the .exe file to install and follow the prompts for installation.

If you are using Mac OS X: click on "Download R for (Mac) OS X" and on the first .pkg file under Files (currently R-3.3.2.pkg) to download. If you have an older Mac OS X release, follow the appropriate instructions. Follow prompts for installation.

If you are using Linux: click on "Download R for Linux", then click on the relevant distribution, and follow the prompts for installation.

You can refer to the frequently asked questions (FAQs) if you have any issues with installation or use: *https://cran.r-project.org/faqs.html*

If you want to explore or modify the R script further, we recommend downloading a program called Rstudio *(https://www.rstudio.com/)*, which has a more accessible graphical user interface. However, this is not necessary to run the script and generate the risk profiles.

2. Preparation of data in Excel

The data needs to be in a specific tabular format and requires export from an Excel to a CSV file in order for the R script to access your data. This section details the requirements of the data files and how to generate them. You will generate two CSV files, both of which are needed for the script.

There are three levels of indicator data: the individual indicator values (Level 2), the subcategories (Level 1), and the overall categories (Level 0). The subcategories and categories will consist of data aggregated from the individual indicators in the quantitative risk assessment, which will themselves be transformed into usable values, following the workflow for vulnerability assessment (see Step 3.2 – Option 3 – #5). The data at any of these levels can and should be changed in the data file to reflect the characteristics of your study system.

The indicator data must be in normalized form (i.e. scaled to a value between 0 and 1 so that all indicators have an identical range) and a weighting scheme must be supplied (but not yet applied). The remaining steps discussed in Step 3.2 – Option 3 –

#5, including weighting of values and aggregation, are carried out in the R script and do not need to be done manually.

Please input your data in the template Excel document provided (Folder "Resources", file "indicator_ template.xls"). The template has two sheets, "IndicatorValues" and "IndicatorLevelsAndWeighting". Each of these sheets will ultimately become a separate CSV file after following the steps below.

IndicatorValues | IndicatorLevelsAndWeighting

	A	B	C
1	adminunit	ES_InsSet	ES_ADP
2	AdminUnit1	0.488874	0.714286
3	AdminUnit2	0.461628	0.555556
4	AdminUnit3	0.298201	1

For the "IndicatorValues" sheet: Input the names of the administrative units in the column "adminunit". Fill in the names of the indicators from your risk assessment as the column names. Fill in the values corresponding to each administrative unit and indicator – these values must already be normalized to a value between 0 and 1, but not yet weighted within their (see Step 3.2 – Option 3: Quantifying vulnerability based on indicators, 5 Compiling and mapping vulnerability).

IndicatorValues | IndicatorLevelsAndWeighting

	A	B	C	D
1	Level0	Level1	Level2	Weight in sublevel
2	Exposure	ES_index	ES_InsSett	0.6
3	Exposure	ES_index	ES_ADP	0.4
4	Exposure	EE_index	EE_AA	0.5
5	Exposure	EE_index	EE_insFar	0.5

For the "IndicatorLevelsAndWeighting" sheet: Input into the sheet the indicator acronyms/names (column "Level2") and the corresponding weighting within the Level 1 subcomponents (column "WeightInLevel1") as previously determined in Step 3.2 – Option 3. Input also the categories to which they belong - Level 0 (column "Level0"), i.e. Exposure, Susceptibility, and Capacity (though this can be modified) and Level 1 (column "Level1"), e.g. Exposure of the Social System (we recommend using a shorter code like ES_index rather than writing out the entire name). The indicator acronyms in column "Level2" must be identical to the corresponding indicator acronyms in the sheet "IndicatorValues" for the script to run properly. For an illustration of the nested categorization scheme, refer to Figure 8.

	A	B
1	adminunit	IndicatorAcronym1
2	AdminUnit1	0.000000

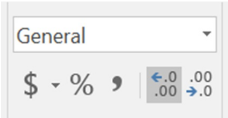
To guide the user with data inputs into the indicator template provided, red triangles indicate commented cells. Click on these for detailed information/instructions.

Indicators and categories at all levels (Level 0, 1, 2) can and should be changed, renamed, added, and removed to make it relevant to your study system. When changing these, please make sure that there are no extra unused rows or columns outside of the data – delete these as necessary.

Ensure that the complete values are showing with appropriate formatting: with the

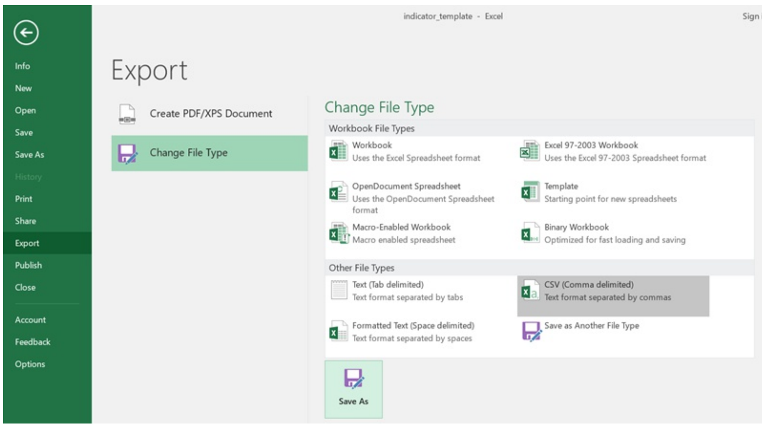
proper number of decimal places and a period (.) instead of a comma (,) as the decimal point (this may be an issue on German or other European systems). Ensure that the amount of indicators and the indicator names match between your two data files.

Solutions for decimal separators: go to File > Options > Advanced > Editing Options > Use system separators and change the separators; for decimal places: on the Home tab, adjust the decimal places as necessary to display the full value.



Troubleshooting if R script does not run properly: Ensure that there are no extra columns or rows outside of the data cells themselves. Extra rows or columns may even appear blank, but if they are there they will cause the R script to attempt to read them as data and fail. There should not be any extra cells in the template file, but if the script is not running properly and generating outputs, extra cells may have been created or left in inadvertently during your editing. Make sure unused rows and columns are deleted. If that doesn't work, try highlighting a few blank rows or columns outside of the data area and delete them.

Once the data has been inputted, export the two sheets of the Excel file to two CSV files for use with the R script. To export the Excel files in a usable format, go to File > Export > Change File Type > select CSV (Comma delimited) and save only the active sheet to a CSV when prompted. Make sure to save the file name to reflect its contents, i.e., to differentiate between the sheet with indicator values and the sheet with levels and weighting. Repeat this for the other sheet. You should now have two separate CSV files ready for use with R. Move both of these CSV files to the desired destination folder for your risk profile outputs.

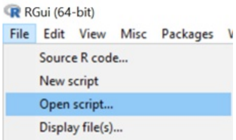


Example data has been provided in the Resources folder in case you would like to try out the script and view example outputs without your own data. However, do not use this data or its outputs in your planning, as you need to derive data that represent your study area. The example data is in two CSV files: indicator_exampledata_values.csv and indicator_exampledata_levelswts.csv. To use these, input these as the data file names in Step 4.3.3 – Load your data.

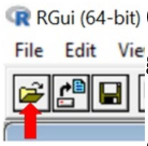
3. Running the R Script

Once you have R downloaded, and have already prepared the data in Excel, open the R script for risk profile generation. When you run the script, it will automatically load and install the necessary plug-ins. The script has automated the data manipulation and transformation as well as the generation of risk profile graphics, and requires only basic inputs from the practitioner.

1



2



Once you have downloaded R as per the Step 4.3.1 guidelines, start R and then either 1) navigate to File > Open Script or 2) click on the folder icon to open script. Navigate to your R script file and open.

Once you have opened the script in R or RStudio (or another interface for R), you only need to enter information where it is marked with “! USER INPUT REQUIRED“ at the beginning of the script. After “NO MORE USER INPUT REQUIRED AFTER THIS POINT“, you do not need to change anything in the script unless you have experience coding in R and want to change settings like colors.

Set your working directory:

This tells the script where to look for your files on your computer and directs it to a particular folder. This folder should contain the two CSV files you prepared in Step 4.3.2, and it will also contain all of the outputs generated when you run the script.

To set the path name: Go to the file in the folder. Right-click on the file name and navigate to Properties. Copy the path name under Location and paste into the R script. On Windows, you must change the \ to / in order for this to work. You must have the quotation marks “ “ around the path name.

Example: setwd(“C:/Users/yourusername/Documents/WASCAL”)

```
# --------------
# GENERAL SET UP
# --------------

# Set working directory and libraries
# -----------------------------------
# "setwd" tells the script where to look for your files on your computer
#     and directs the script to a particular folder (the working directory).
# This working directory is where it will access all your data files
#     and also store all of your outputs (the risk profiles).
# The script has been built to process the data with minimal effort,
#     but without this critical step, it cannot access the data and will not ru
# To set the path name: Go to any file in the folder. Right-click on the file r
#     Copy the path name under Location and paste into the R script on line 19.
#     On Windows, you must change the \ to / in order for this to work.
#     You must have the quotation marks " " around the path name.

# ----- ! USER INPUT REQUIRED: SET WORKING DIRECTORY
setwd("C:/Users/yourusername/Documents/WASCAL")
```

Load your data:

You must now specify which files in this folder you want the script to access.

Copy the name of the file, including the file extension (.csv). Paste it into the R script as specified.

Example: if your indicator values file is called IndicatorValues.csv and your indicator levels and weighting file is called IndicatorLevelsAndWeighting.csv, it should look like this (make sure it is surrounded by quotation marks, and pay attention to case):

indicfile = read.csv("IndicatorValues.csv")

indiclevels = read.csv("IndicatorLevelsAndWeighting.csv")

The script has been written such that it will draw the data from whatever you input as indicfile and indiclevels. Do not change the variable names, only the file names within the quotation marks!

```
# Within this working directory, you must specify the files that contain your data.
# Load both data files: 1) raw indicator values and 2) indicator levels and weights.

# ----- ! USER INPUT REQUIRED: ACCESS DATA FILES
# Indicator values:
indicfile = read.csv("IndicatorValues.csv")
indicfile
# Indicator levels and weights:
indiclevels = read.csv("IndicatorLevelsAndWeighting.csv")
```

Specify categories for which to calculate the inverse:

Set the Level 0 categories for which the inverse needs to be computed. The default is "Capacity" only. The reason for this is that exposure and susceptibility both contribute directly to the risk profile (they increase vulnerability) while capacity decreases vulnerability and therefore needs to be converted to a lack of capacity (which increases vulnerability) for the risk profile. For example, an overall capacity of 0.6 actually indicates a lack of capacity of 0.4. Specifying "Capacity" (or any other category/categories as needed) for this setting activates the conversion to the inverse, or lack of that component, and allows it to contribute directly to the risk profile. See the equation from Step 3.2 – Option 3. Any other variable category that would appear in this equation as (1 – Category) should be added into the code here.

```
# Set Level 0 categories that must be converted to the inverse
# ------------------------------------------------------------
# Optional setting, but requires input.
# See WASCAL handbook for details:
# Must any of your Level 0 categories be converted to the inverse?
# I.e., capacity must be converted to a LACK of capacity
# If so, please specify here; if there are multiple categories, add a comma like so:
#     inverse_level0 <- c("Capacity", "Exposure") and so on.
# The name must exactly match what is in your indicator levels and weights file.
# If there are no Level 0 categories which must be converted to the inverse,
# delete the contents like so (do not delete the lines of code):
#     inverse_level0 <- c()

# ----- ! USER INPUT REQUIRED: CATEGORIES TO COMPUTE INVERSE
inverse_level0 <- c("Capacity")
```

Specify order of Level 0 categories in risk profile output:

Set the order in which you want the Level 0 categories to appear in the risk profile outputs (pie charts, bar plots, and tables). The default is Hazard followed by Exposure, Susceptibility, and Capacity as per the conceptual framework for risk and vulnerability. This is purely a visual setting and has no impact on how the data is analyzed. However, you must set this with the exact names of the Level 0 categories in some order to allow the R script to process properly.

No more user input or script modifications are required after this point, and any optional alterations (such as to the color scheme or other formatting) should only be attempted if you are comfortable writing scripts in R. The script will automatically transform the raw data into usable percentage contributions and generate a graphic risk profile and table of transformed values for each administrative unit in your CSV file.

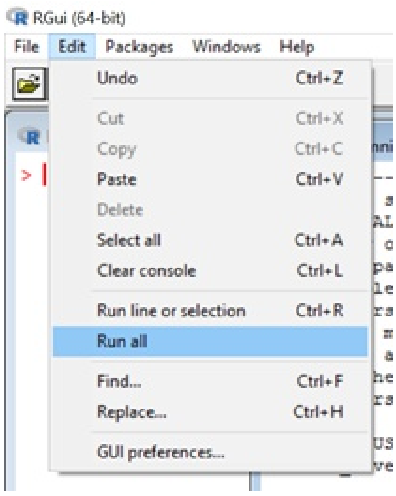
```
# Set order of Level 0 categories
# -------------------------------
# You must also specify in what order you would like the Level 0 categories to appear in the
# risk profile. You may leave this as the default order or change it as needed.
# The default order is: exposure, susceptibility, capacity, and then hazard.
# You MUST change this to reflect your Level 0 categories.
# For example, if you do not have the hazard category in your data, you MUST delete it like so:
#      level0order <- c("Exposure", "Susceptibility", "Capacity")

# ----- ! USER INPUT REQUIRED: ORDER OF LEVEL 0 CATEGORIES
level0order <- c("Hazard", "Exposure", "Susceptibility", "Capacity")
```

To run the R script:

In the basic R software, select to Edit > Run all.

As an alternative, and for Rstudio if you are using it, first select all (CTRL+A) and then run (CTRL+R).



The R script will transform the normalized data as follows, based on the necessary transformations specified in Step 3.2 – Option 3:

1. Weight each normalized indicator value by multiplying by a percentage according to a predetermined weighting scheme, such that the new value (still) lies between 0 and 1 - this represents the contribution that the individual indicator makes to the subcategory.

2. Each transformed indicator value will be transformed again (divided by n) according to how many indicators are in the subcategory (n). These twice-transformed values add up to give a preliminary value for the subcategory. The subcategories again add up to give a preliminary value for the category. However, these will not add up to 100 and thus need to be transformed again in the next step so that they can be properly displayed in the risk profile chart as a percentage.

3. The values for the three categories shall be summed, and a 100% reference value established by dividing this sum by 100. The value for each category is then multiplied by this 100% reference value to generate new values for each category and subcategory, which will finally sum up to 100%.

4. These percentages will be used to generate a pie chart, bar plots, and tables of contributions to the overall risk profile by each indicator and category.

Outputs:

The R script will output two PDF files per administrative unit: one with the pie chart and bar plots, and one with tables indicating the percent contributions to the risk profile of each subcomponent of vulnerability. All outputs are saved to the working directory specified in the R script, and all names (of administrative units and indicators) correspond to the information in the data files. All PDF output files are A4-sized.

Files named RiskProfile for [administrative unit name, as specified in CSV for indicator values] – see below. These graphic risk profiles are intended to quickly highlight which indicators contribute most to the overall risk.

This output file includes a pie chart with the Level 0 and Level 2 contributions to the overall risk profile for the administrative unit. The Level 0 categories (inside pie chart) are labelled by name and the percentage contribution. The Level 2 indicators (outer ring) are labelled with a number for identification purposes and are colored according to the Level 1 category – these correspond to the bar plots.

Below the pie chart are the bar plots, one for each Level 0 category. The bars represent the Level 2 indicators and their contributions to the overall risk profile (which can be gleaned from the x-axis) and are labelled by name within each bar and by number (corresponding to the pie chart) on the y-axis before each bar. They are colored according to the Level 1 categories to which they belong, and these are also labelled on the y-axis. For precise percentage values, refer to the PDF of tables (see below).

Part I

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Step 4
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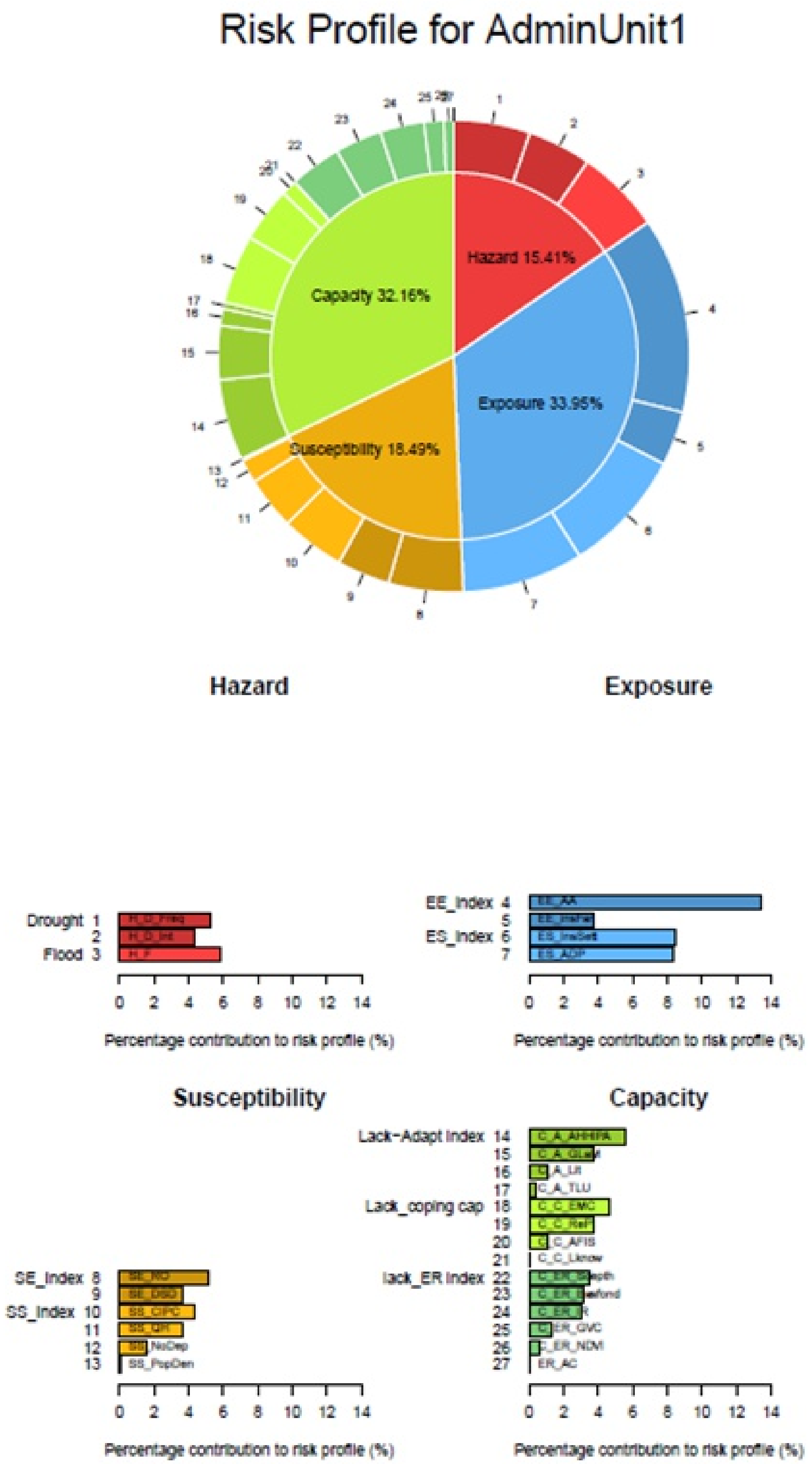

Part I

Files named TransformedValues_[administrative unit name, as specified in CSV for indicator values] – see below. They are intended to supplement the graphic risk profiles when precise values are desired or required.

These tables indicate the percentage contribution to the overall risk profile for each indicator at each level (Levels 0, 1, and 2). Level 0 percentage contributions are in the top left corner (the smallest table), Level 1 is in the bottom left, and Level 2 (the biggest table) is on the right.

With the two PDF files per administrative unit generated automatically by the script, the folder you set as your working directory should contain the files like so:

Risk Profile for AdminUnit1: Percentage Contributions

	Level0	Percent
1	Hazard	15.41
2	Exposure	33.95
3	Susceptibility	18.49
4	Capacity	32.16

	Level0	Level1	Percent
1	Hazard	Drought	9.60
2	Hazard	Flood	5.81
3	Exposure	EE_index	17.13
4	Exposure	ES_index	16.82
5	Susceptibility	SE_Index	8.75
6	Susceptibility	SS_Index	9.74
7	Capacity	Lack~Adapt index	10.84
8	Capacity	Lack_coping cap	9.54
9	Capacity	lack_ER index	11.78

	Level0	Level1	Level2	Percent
1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]
14	Capacity	[illegible]	[illegible]	[illegible]
15	Capacity	[illegible]	[illegible]	[illegible]
16	Capacity	[illegible]	[illegible]	[illegible]
17	Capacity	[illegible]	[illegible]	[illegible]
18	Capacity	[illegible]	[illegible]	[illegible]
19	Capacity	[illegible]	[illegible]	[illegible]
20	Capacity	[illegible]	[illegible]	[illegible]
21	Capacity	[illegible]	[illegible]	[illegible]
22	Capacity	[illegible]	[illegible]	[illegible]
23	Capacity	[illegible]	[illegible]	[illegible]
24	Capacity	[illegible]	[illegible]	[illegible]
25	Capacity	[illegible]	[illegible]	[illegible]
26	Capacity	[illegible]	[illegible]	[illegible]
27	Capacity	[illegible]	[illegible]	[illegible]

The graphic risk profiles, which include the pie chart and bar plots, are named RiskProfile__[administrative unit name, as specified in CSV for indicator values]. There will be one risk profile PDF for each administrative unit specified in the data files.

RiskProfile_AdminUnit1	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit2	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit3	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit4	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit5	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit6	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit7	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit8	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit9	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit10	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit11	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit12	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB
RiskProfile_AdminUnit13	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB

The tables that display the percentage contribution for each indicator at each level (Levels 0, 1, and 2) are stored in a file named TransformedValues_[administrative unit name, as specified in CSV for indicator values]. There will be one transformed values PDF for each administrative unit specified in the data files.

TransformedValues_AdminUnit1	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit2	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit3	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit4	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit5	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit6	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit7	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit8	5/16/2017 12:12 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit9	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit10	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit11	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit12	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB
TransformedValues_AdminUnit13	5/16/2017 12:13 AM	Adobe Acrobat Docu...	10 KB

Conclusion (WASCAL handbook part I)

Part I of the handbook on Risk Assessment in West Africa documents a practitioner-oriented, step-by-step procedure on how to conduct risk assessment, with examples from case studies in West Africa and for the climate-related hazards floods and droughts. This handbook offers various options to conduct risk assessments both in qualitative or quantitative manners which require different professional expertise and backgrounds as reflected by the various options presented. The design of the handbook as a living document allows for methodological procedures to be adjusted during the application of the suggested steps and depending on relevant scientific advances, allowing for a continuously up-to-date document.

The current version of this handbook has been discussed with stakeholders from Benin, Burkina Faso and Ghana that were involved in disaster risk management. Through the process of preparing this handbook – published both in English and French - stakeholders argued that a common structured procedure for a regional assessment in the Anglophone/Francophone region of West Africa should be promoted and that the handbook specifically use as communication tool for transboundary collaboration. As natural hazards often hits regions across country boundaries, this tool is of high relevance. In addition, this handbook can be used to complement hazard early-warning systems that are in place in most of the countries, and allows to take the next step from re-active disaster risk management to pro-active disaster risk prevention and reduction.

After conducting a risk assessment as described in this handbook, you have a wealth of information, which allows you to identify high risk zones, most vulnerable population groups and economic sectors for selected hazards. This information should inform the selection of suitable adaptation measures and areas or target groups of priority. In addition, the assessment provides a baseline information which can be used for (i) monitoring risks in the future through repeated risk assessments and (ii) evaluating the effect of implemented adaptation measures towards disaster risk reduction.

Imprint

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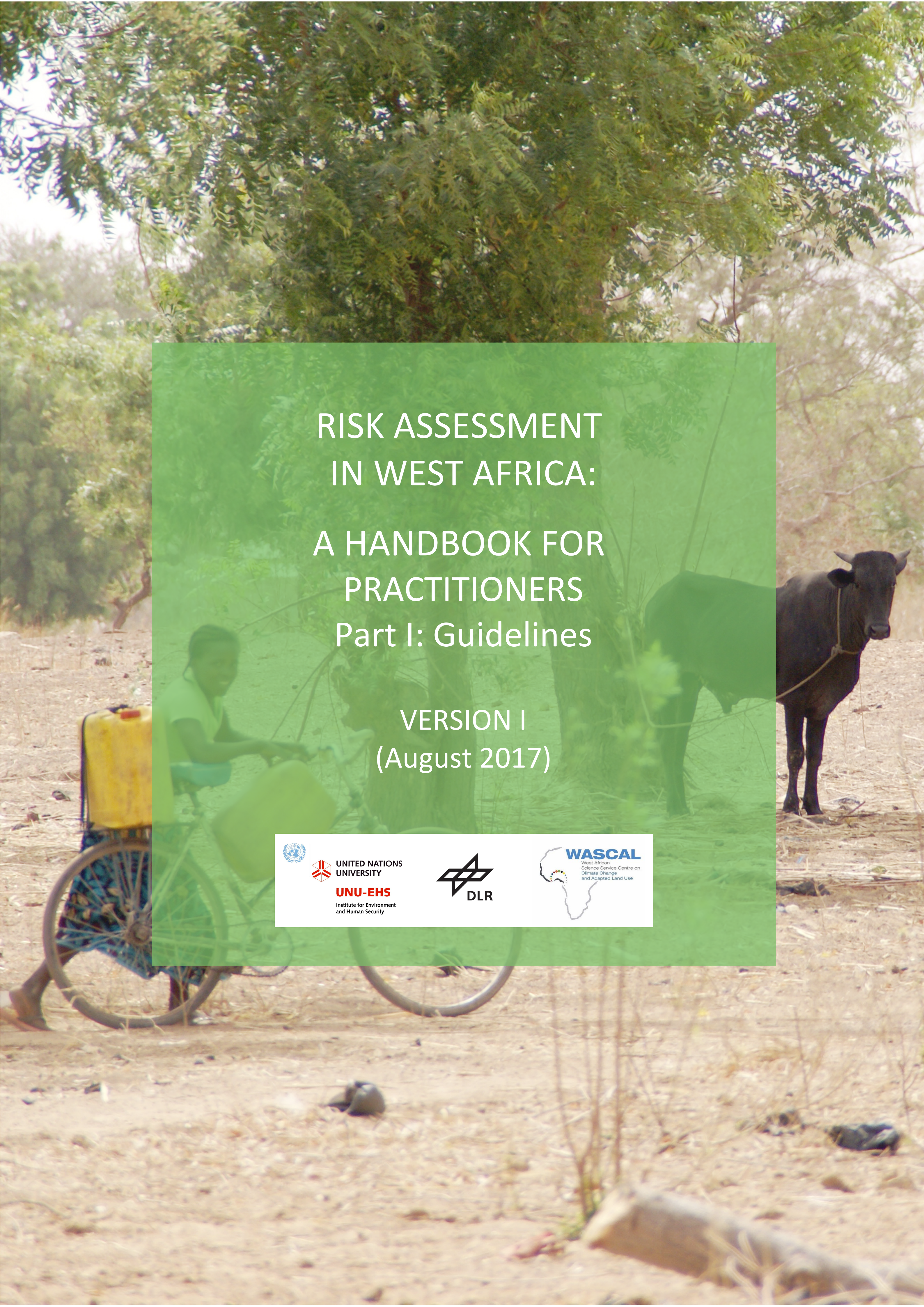

RISK ASSESSMENT IN WEST AFRICA:

A HANDBOOK FOR PRACTITIONERS
Part I: Guidelines

VERSION I
(August 2017)

UNITED NATIONS UNIVERSITY
UNU-EHS
Institute for Environment and Human Security

DLR

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