Mapping Social-Ecological Vulnerability to Flooding

by Marion Damm

A sub-national approach for Germany

GRADUATE RESEARCH SERIES
PHD DISSERTATION

Vol. 3

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

GRADUATE RESEARCH SERIES
PHD DISSERTATIONS
Publication Series of UNU-EHS
Vol. 3

UNU-EHS
Hermann-Ehlers-Str. 10
53113 Bonn, Germany
Tel.: + 49-228-815-0200
Fax: + 49-228-815-0299
E-mail: info ehs.unu.edu
www.ehs.unu.edu

Cover Photo: Shutterstock
Cover Design:
Andrea Wendeler
Layout: Andrea Wendeler
Copy-Editing: Anchor English
Proofreading: Katharina Brach

ISBN: 978-3-939923-46-6
e-ISBN: 978-3-939923-47-3
ISSN: 2077-737X
Printed at Druckerei
Paffenholz, Bonn, Germany
December 2010
500 print run

This dissertation was first published online at http://hss.ulb.uni-bonn.de:90/2010/1997/1997.htm.
For publication in the UNU-EHS Graduate Research Series, the manuscript was slightly revised for editorial purposes.

Marion Damm

About the author

Marion Damm is working for the Climate Protection unit in the Bavarian State Ministry of Environment and Public Health in Munich. She is coordinating the European Union project AdaptAlp which deals with adaptation of natural hazard management to the challenges of a changing climate in mountainous regions. As an expert for climate adaptation and natural hazard and risk management she transfers scientific results and findings in policy relevant information.

Mrs. Damm holds a diploma in Physical Geography from the Ludwig-Maximilians-University in Munich and earned her PhD from the Department for Geodesy and Geoinformation at the Friedrich-Wilhelms-University in Bonn. The dissertation was conducted and supervised at the United Nations University Institute for Environment and Human Security (UNU-EHS). Her PhD research focuses on the development and mapping of vulnerability indicators for flood-prone areas in Germany. The sub-national approach enables to compare vulnerable regions across Germany.

Mapping Social-Ecological Vulnerability to Flooding

A Sub-National Approach for Germany

Marion Damm

In Cooperation with

universitätbonn

Graduate Research Series vol. 3 and vol. 4 were conducted within the framework of the DISFLOOD project.

Acknowledgement

The writing of this dissertation has been one of the most significant academic challenges I have ever faced. Without the support, patience, and guidance of the following people, this study would not have been completed.
I owe them my deepest gratitude:

- Prof. Janos Bogardi who undertook to act as my first supervisor despite his many other academic and professional commitments. His wisdom, knowledge, and commitment to the highest standards strongly motivated me.
- Prof. Theo Kötter who was willing to take over the co-reference of this dissertation.
- My sincerest thanks go to Dr Fabrice Renaud who acted as academic supervisor during the various stages of my study. His invaluable guidance, advice, and support strongly contributed to the success of this study.
- Dr Jörn Birkmann for his important recommendations and suggestions.
- The supervisors of the Disaster Information System for Large-Scale Flood Events Using Earth Observation (DISFLOOD) project, the Natural Disaster Networking Platform (NaDiNe) team, and in particular Hendrik Zwenzner, Steffi Uhlemann, and Alexander Fekete for their support, criticisms, and the stimulating working atmosphere.
- All data providers and interview partners who were willing to share their data, documents, and invaluable expert knowledge with me.
- My friends and colleagues at UNU-EHS, who motivated me with their scientific enthusiasm and provided me with mental support.
- Special thanks to my dear colleagues in the PhD lab. I will always remember the time we spent discussing, arguing, and laughing.
- My family and friends in Munich and Augsburg who have always supported, encouraged, and believed in me and in all my endeavours.

This study was financed by the Helmholtz-EOS PhD programme. I would like to thank the EOS administration for their financial support during the years of 2005 and 2009.

Foreword

Floods are a worldwide concern and, as recent events in Europe have reminded us, no country can consider itself immune to the impacts of flooding. Germany has suffered from serious flood damages in the past such as the 2002 Elbe and Danube floods and many research activities are now addressing this hazard. One such activity was the DISFLOOD project, which was funded by the Helmholtz Association and executed by the German Aerospace Center (DLR), the GeoForschungsZentrum Potsdam (GFZ) and UNU-EHS. The project, which results are now hosted on the NaDiNe Platform, aimed at investigating new tools to provide Germany-wide information on vulnerability at regional scale while at the same time enabling rapid flood hazard mapping and large-scale flood event scenarios. The collaboration between all involved partners was optimal and allowed for a real integration of various research streams spanning the social and natural sciences. Most of the research was carried out by four PhD Researchers, one of them being Dr Marion Damm who was based at UNU-EHS.

Through her PhD research, Dr Damm addressed a set of complex issues related to vulnerability assessment. First of all, she strived to consider complex social-ecological systems represented in her work by the forest and agricultural sectors, not an easy task in itself. Second, she worked at the district level to map the vulnerability of the two sectors with all the data problems this entailed. The research was grounded on the theory of the SUST framework from Turner and co-workers, which Dr Damm modified to serve the purposes of her research. In order to map the vulnerability of the two sectors mentioned above for Germany, indicators were derived and here Dr Damm followed very rigorous procedures to first select the indicators (through literature review and expert interviews), normalizing the indicators, weighing and aggregating them to create a set of composite indicators. For most of these steps, Dr Damm tested different methods basing her final approach on the most promising ones. The end product is a set of maps that enables the visualization of vulnerability at the district level with the maps being able to display the main components of vulnerability of the modified SUST model such as exposure, susceptibility and capacities.

The results from Dr Damm's work not only illustrate the vulnerability of the forestry and agricultural sectors to floods in Germany but also show in some details the underlying reasons for this vulnerability. The maps generated through this research are updatable and can therefore be re-edited regularly. The rigour of the approach used by Dr Damm which is depicted in this dissertation also sets a good example for scholars dealing with vulnerability indicators.

Dr Fabrice Renaud
Head of Environmental Vulnerability
& Energy Security Section (UNU-EHS)
Academic Supervisor

Prof. Janos J. Bogardi
Senior Advisor to the Rector (UNU)
First Supervisor (Referent)

Abstract

In recent decades, river flooding has produced immense economic and ecological damage in Germany. Therefore, disaster management aims at detecting vulnerabilities and capacities in order to reduce flood disaster risk. This study contributes to the mapping of social-ecological vulnerability at a sub-national scale through the development of appropriate tools and methods. Vulnerability is assessed for the two sectors of ‘forest’ and ‘agriculture’ in this research.

A modified version of the Turner vulnerability model was selected as a conceptual framework for the vulnerability assessment. The model depicts processes and characteristics of social-ecological systems (SESs) and defines vulnerability as being composed of exposure, susceptibility, and capacities. Although some analytical limitations could be detected in the framework, such as a missing definition for ‘risk’ or strong interrelations between the components of ‘susceptibility’ and ‘capacities’, the model acted as a valuable framework and was also successfully operationalized. Indicators were used as tools for assessing vulnerability at regional level. Indicators simplify complex issues and thus make the notion and concept of vulnerability understandable and accessible for practitioners. The development of indicators was effected through a number of consecutive work steps including impact analysis, the building of vulnerability categories, the identification of indicators, and the collection of data for mapping vulnerability. Expert interviews and a literature review were carried out to gather all necessary information. Fifteen indicators were finally selected to assess the vulnerability of the agricultural sector, and 14 to represent forest sector vulnerability.

Mapping the vulnerability of the two sectors, agriculture and forest, across districts required the development of a composite indicator for each sector. Therefore, single indicators were normalized, weighted, and aggregated. After a careful evaluation of the various methods, the ‘weighted sums’ technique was applied to build the composite indicators. A Geographical Information System (GIS) facilitated the calculation and mapping of the components of ‘exposure’, ‘susceptibility’, and ‘capacities’ as well as the ‘vulnerability’ composite indicator. Thus, vulnerable hot spots can be easily detected and visualized. The produced maps reveal that most hot spots are located in the ‘new federal states’. This is not completely unexpected, since east Germany has not yet fully recovered in terms of socio-economic standards since the reunification in 1990. By combining the hazard characteristic ‘inundation extent’ with vulnerability in districts along the rivers Elbe and Rhine it could be shown that in the case of data availability, risk maps can easily be produced in a GIS.

Some analytical shortcomings and technical inaccuracies could not be avoided during the vulnerability assessment. For that reason, the approach was thoroughly evaluated to verify the assessment and quantify uncertainties. The approach was tested for its feasibility, conceptual underpinning, data basis, and its methodological robustness. Furthermore, sensitivity and uncertainty analyses were conducted. Methods and techniques turned out to be sufficiently robust. In future, however, a clear analytical distinction should be made between the two components ‘susceptibility’ and ‘capacities’ to avoid coupling effects.

Table of Contents

1. Introduction

1.1 Flood disasters in Germany

During recent decades, Germany has repeatedly suffered tragic loss of life, massive economic damage, and severe environmental losses due to catastrophic flooding. In August 2002, scenes of devastated cities, villages, and landscapes were flashed around the world, with economic costs estimated in billions of euros (see Table 1.1). Coming just five years after the floods that caused havoc across central Europe in the summer of 1997, and less than a decade since dramatic floods along the lower and middle courses of the river Rhine, people wondered why such events seemed to be happening more often, causing more damage than in the past, and how they could be better dealt with.

Floods are natural phenomena which occur from time to time everywhere that rivers exist. However, as natural floodplains and river courses in Germany have been heavily transformed by human intervention, especially since the beginning of the industrial revolution in the 19th century (Turner et al. 1990), the natural environment cannot buffer and absorb flooding that easily any more. Moreover, floodplains are used intensively as areas for settlement and for the production of food, timber, and water. The interventions in the natural system as well as the dependency on the floodplains' productive, regulatory, and protection functions make the human system additionally susceptible to the hazardous event of 'river flooding'. Therefore, a naturally-induced hazard is more likely to become a 'social disaster' (Colding et al. 2003; Felgentreff and Glade 2008).

Due to global climate change, hydrological and meteorological variables and patterns have been changing. Different regional models have calculated dramatic impacts of the rising temperature on precipitation and run-off (e.g. Kotlarski et al. 2005; Spekat et al. 2006). Although there are still great uncertainties in the results of these models, it is necessary to take possible changes of flood intensity or occurrence into consideration and to avoid exclusively relying on conventional strategies. It is highly probable that the mixture of natural variability and human interference is responsible for human suffering and financial losses to millions of people and industries, as well as severe environmental losses across the country (WWF European Policy Office 2004).

Responding to the enormous damage and the people's demand for enhanced flood disaster management in Germany, a rethinking of actions and management is taking place. Some people even believe a paradigm shift has been occurring in the German society. Whereas in the past, control of river floods by technical protection measures (dams, dykes, river regulation) was given priority and flood response was seen as an essential part of flood protection, the focus today has shifted towards the idea of an integrative flood management combining flood prevention and preparedness jointly with reactive emergency relief measures (Birkmann 2006b; Merz 2006).

The political response to the demand for integrative flood management is reflected by the recent ratification of several guidelines, laws, and directives dealing

Table 1.1: Economic damage of the most severe flood events since 1990 in Germany

Rank	Month/Year	Catchment Areas	Damage [m. €]	Insured damage [m. €]
1	08/2002	Elbe, Danube	11600	1800
2	12/1993	Rhine	530	160
3	05/1999	Danube, Rhine	430	75
4	07/1997	Oder	330	32
5	01/1995	Rhine	235	95

Source: Munich Re (oral communication)

with flood risk and flood management at European and German level. Examples are the 5-Point Programme of the German Government[1], the Act on Flood Protection[2], and the recently published directive of the European Commission on the assessment and management of flood risks[3]. These were released to improve preventive flood management and to enhance cooperation between politics, science, and public. Due to the European Flood Directive, flood hazard and flood risk maps have to be developed by the end of 2011 and flood risk management plans are supposed to be drawn up by 2015.

DISFLOOD is one research project that was set up as a reaction to the political and scientific discussion on the development of methods and applicable tools for the assessment and mapping of flood risks in Germany (Damm et al. 2006). The project aims at filling an important gap in Germany, namely the lack of a tool providing Germany-wide information on multi-dimensional vulnerability at regional scale on the one hand, as well as rapid flood hazard mapping and large-scale flood event scenarios on the other. Since this project understands flood risk as a combination of hazard and vulnerability it should enhance flood risk assessment in Germany.

This dissertation emanates from the scientific work on this project and mainly addresses the assessment of social-ecological vulnerability to river flooding at sub-national level.

1.2 The Social-Ecological System 'floodplain'

When a flood event strikes, it is not only settlements that are heavily affected; it also, or sometimes in particular, has an impact on areas of open space in river floodplains. In Germany, such open space usually covers around 90 % of such land area. Floodplains are a typical example of a social-ecological system (SES) which is "a system of people and nature" (Carpenter 2008), or a system where people and nature interact with and influence each other. The Millennium Ecosystem Assess-

---

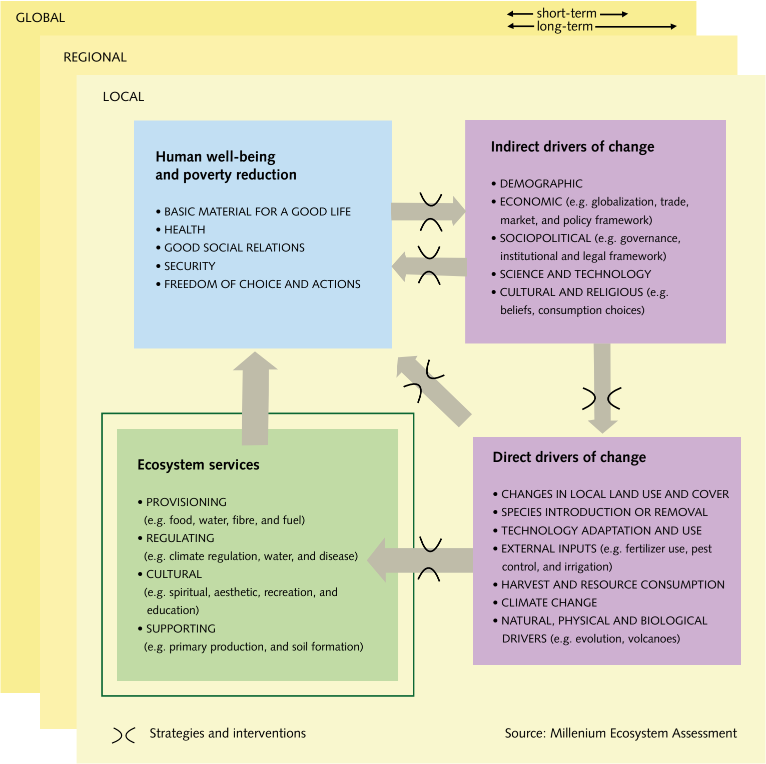
[1] more information on http://www.bmu.de/gewaesserschutz/doc/3114.php

[2] more information on http://www.bmu.de/english/water_management/downloads/doc/35456.php

[3] more information on http://ec.europa.eu/environment/water/flood_risk/index.htm

ment published a framework showing the dynamic interrelations between ecosystems and people (see Figure 1.1). This framework can easily be transferred to the social-ecological system ‘floodplain’ where similar interactions take place.

Figure 1.1: Conceptual framework of Millennium Ecosystem Assessment



Source: MEA 2003

Floodplains provide a broad range of ecological and socio-economic goods and services, including, for instance, food production, groundwater replenishment, and recreational values which directly contribute to human well-being by assuring health, material, or good social relations. Yet, indirect drivers such as demographic and economic changes influence land use decisions, technological development, or harvest consumption which again directly influence ‘Life on Earth’ as well as human well-being. Natural physical drivers, such as flood events, are also understood as direct drivers of change affecting ecosystem services and humans.

The World Wide Fund for Nature (WWF) estimates that approximately 80 % of natural inundation areas have been lost in Germany during the last few centuries

(WWF Deutschland 2007) due to the implementation of river control measures and construction of embankments. Therefore, it is not surprising that overtopped or breached levees cause severe adverse impacts on the social-ecological system. During the Elbe flood in 2002, numerous dykes were breached, and in the federal state of Saxony-Anhalt alone, 55,000 ha were flooded, including 40,000 ha of arable land (IKSE 2004). The forestry and agricultural sector recorded monetary losses of € 71 million. However, direct monetary losses in terms of crop loss and damaged infrastructure are only the easily quantified losses. Long-term effects such as contamination or erosion, as well as short-term effects such as loss of recreational functions also need to be taken into account when the whole picture of flood impacts and consequences are analysed.

An ongoing scientific discussion on the topic of coupled processes in social-ecological systems (Berkes et al. 2003; Berkes and Folke 2000), social-ecological resilience (Adger 2000; Folke 2006; Gunderson and Holling 2002), and social-ecological vulnerability (Eakin and Luers 2006) has stimulated the development of various conceptual and analytical frameworks. The objective is to learn more about social-ecological systems with regard to their resilience, capacities to respond, and their system-inherent sensitivities and weaknesses. Yet, applied research that focuses on the operationalization of those frameworks is still rare. Numerous studies exist capturing the social or physical dimensions of vulnerability (e.g. Barredo et al. 2007; Cutter et al. 2003; Kelman 2003; Weichselgartner and Deutsch 2002) focusing mostly on social groups or settlements. On the other hand, several projects and scholars are solely engaged with the ecological impacts (e.g. the project network of 'Elbe Ökologie'[4]) of flooding. Some substantial research has been undertaken on the assessment of vulnerability of particular environmental services towards climate change (ATEAM 2004a; Luers et al. 2003). National indices also exist, such as the Environmental Vulnerability Index (EVI) (Kaly et al. 2004) that integrate various environmental and social aspects in their approach. However, an applied approach targeted at the assessment of social-ecological vulnerability to flooding in Germany has not been carried out before. This study attempts to fill this gap by performing the following tasks:

- Identifying an appropriate theoretical and analytical framework
- Developing and identifying adequate methods
- Conducting regional analyses
- Mapping social-ecological vulnerability.

1.3 Research questions

In order to fulfil the overall research objective of mapping and localizing regional vulnerable 'hot spots' in Germany, the following research questions are addressed in this dissertation:

---

[4] More information on http://elise.bafg.de/servlet/is/213/

Broad research question:

How can social-ecological vulnerability to river flooding be captured and visualized at the regional scale?

Specific research questions:

1. How can the concepts of vulnerability and social-ecological systems be linked to each other?
    - What are the important elements?
    - What are the dynamics?
    - What are the boundaries?
2. Which conceptual framework facilitates best the assessment of social-ecological vulnerability?
    - Which one reflects all necessary aspects?
    - Can it be easily operationalized?
3. Which indicators are able to capture social-ecological vulnerability?
    - How can they be identified?
    - Which criteria have to be fulfilled?
4. What is the best methodology to create a vulnerability index?
    - How can vulnerability be quantified?
    - What data is available?
    - How can vulnerability be visualized?
5. How can the quality of the approach be evaluated?
6. Is the developed approach transferable to other countries?

1.4 Research challenges

A regional approach is conducted in this research, and this enables the detection of large-scale patterns, captures the vulnerability for the whole country, and provides transferable rather than site-specific information. However, a regional approach is also very challenging as the scholar has to face major constraints.

The quality of the vulnerability assessment is mainly dependent on the quality and quantity of information and data that is available. A Germany-wide regional approach requires the availability of data sets and of course accessibility as well. In Germany, much data exists, but its value is often limited by high access costs or data inconsistency. Data is mostly held by federal states, which complicates collection as some federal states have their own regulations and standards. The collection of qualitative information is constrained by the necessary generalization of a regional approach. Experts need to be found who have not only local knowledge but who can also capture the regional context. Moreover, this approach attempts to compromise between the high complexity of processes in SES and the necessity to simplify in order to map vulnerability at regional level. Indicators are valuable tools for the assessment and mapping of vulnerability, but it must be remembered that the identification of indicators is a complex and iterative process that requires adherence to certain quality criteria. Furthermore, as a practitioner-oriented approach is targeted, indicators have to be understandable, reproducible, and most importantly, relevant. Finding indicators that fulfil those criteria is seen as a further research challenge.

Inevitably, indicator development and the creation of a composite vulnerability index are based to a certain extent on subjective decisions and personal judgment. Therefore, it is crucial to validate the outcomes thoroughly. However, conventional validation of vulnerability is not possible, since vulnerability cannot be measured in the traditional sense. Thus, another methodology has to be developed to handle the evaluation of the results or the entire approach. One of the objectives of this study is to develop and propose methods to evaluate the research results to ensure scientific soundness and quality.

The conceptualization of social-ecological vulnerability is also challenging. A framework needs to be identified or developed that on the one hand incorporates all necessary components and dynamics but on the other hand can easily be operationalized. A first review has shown that a variety of concepts already exist referring to the topic of risk and vulnerability; but the more complex a concept is, the more difficult the implementation becomes. Thus the challenge remains to accomplish the task of combining complex conceptual ideas with the practical demand of being able to operationalize them.

Finally, the issue of scale is seen as a major challenge in this dissertation. Multi- and cross-scale approaches have recently been demanded within the research community (oral communication with EWG IV[5]). However, it has to be tested whether it is possible to fulfil these demands in the presented approach.

1.5 Structure of the dissertation

The main body of the dissertation is divided into three parts and is framed by an introduction of the topic and description of the study area at the beginning, and a conclusion and outlook at the end of the work (see Figure 1.2). The introduction provides a brief overview of the background of the study and outlines the research questions and challenges addressed in this dissertation. Moreover, the study area is presented, giving information on social, economic, and environmental aspects of German society.

The first main part is dedicated to the conceptualization of the present research. Theories and conceptual frameworks are reviewed and discussed, and thus

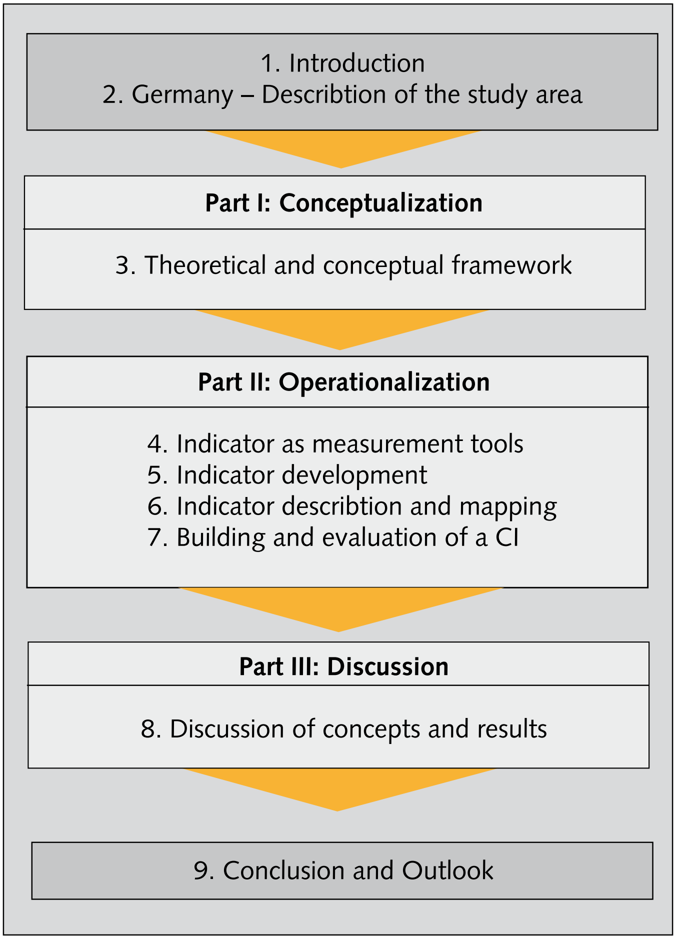
---

[5] Expert Working Group on Vulnerability organized by UNU-EHS (http://www.ehs.unu.edu/article/measuring-vulnerability)

form the basis for the developed research design. The second part deals with the operationalization of the developed concept and presents methods and results. In the individual chapters, the identification of indicators, the development of a composite indicator, and the mapping and evaluation of vulnerability throughout Germany is described. In part III, concepts and results are intensively discussed referring to the research questions set out in the introductory chapter.

The dissertation closes with the chapter 'Conclusion and outlook', which highlights the main findings of the work and proposes possibilities for future research.

Figure 1.2: Structure of the dissertation



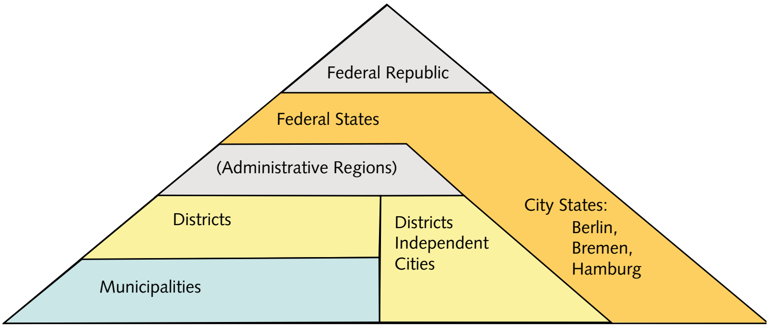
Source: Author

2. Case study area – Germany

2.1. General information

Germany, or officially the Federal Republic of Germany, is located in central Europe. It is bordered to the north by the North Sea, Denmark, and the Baltic Sea; to the east by Poland and the Czech Republic; to the south by Austria and Switzerland; and to the west by France, Luxembourg, Belgium, and the Netherlands. The territory of Germany covers 357,021 km² and is influenced by a temperate seasonal climate. With over 82 million inhabitants, it has the largest population among the member states of the European Union. Furthermore, with 231 inhabitants per km^2, Germany is one of the most densely populated countries in Europe. Germany is a federal parliamentary republic of sixteen federal states (German: Bundesländer), which are further subdivided into 439 districts (German: Kreise) and independent cities (German: kreisfreie Städte). The implementation of federal laws is principally the responsibility of the administrations of each of the federal state. Exceptions are activities for which the entire state is responsible, such as foreign relations and defence. The federal states execute laws as an independent administrative body at federal state level. For example, they are responsible for education, regional planning, and environmental conservation. Districts are at an intermediate level of administration between the federal states and the local/municipal levels. They are responsible for matters such as social welfare, caring for national parks, building of hospitals, and disaster management. Districts share many responsibilities with the municipalities (German: Gemeinden) which represent the lowest level in the four-tiered administrative structure (see Figure 2.1). Examples of activities that are the particular responsibility of the municipalities are waste disposal, provision of electricity and water, etc.

Figure 2.1: Administrative levels in Germany



Source: Author

Germany is the largest national economy in Europe. Its GDP accounts for 2.42 trillion euros (Destatis 2008) and GDP per capita averages € 29,437 (rank 19 worldwide).

2.2 Division and reunification (1945-1990)

The Second World War resulted in the division of Germany into four military zones. The sectors controlled by France, the United Kingdom, and the United States were merged in 1949 to form the Federal Republic of Germany, whereas in the Soviet Zone, the German Democratic Republic was established. The two countries were informally known as "West Germany" and "East Germany". German reunification took place in October 1990 when the five established states of the German Democratic Republic joined the Federal Republic of Germany and Berlin was united into a single city-state again.

However, since the reunification, the 'new' federal states have been facing immense economic and social difficulties. The currency conversion, the breakup of the great industrial combines, and the fact that the former East Germany had no effective government for a period of three months hampered economic reconstruction efforts. Only a handful of eastern firms could compete on the world market; most were inefficient and also environmentally destructive. As a consequence, the former East German economy collapsed, thousands of inhabitants faced unemployment, and the east became heavily dependent on federal subsidies.

Even today there is a significant economic imbalance between former East and West Germany. Moreover, the unemployment rate in the eastern part of Germany is about five per cent higher than in the 'old federal states' (Destatis 2008).

2.3 Major river systems

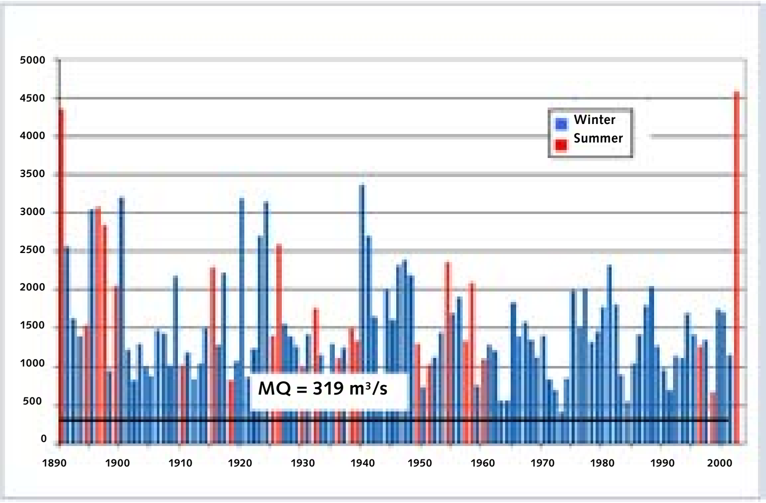
The Danube, Rhine, and Elbe are the three major rivers in Germany. This section provides general information on these rivers. Figure 2.4 shows the respective location and course of each river.

Elbe River basin:

The Elbe River, which stretches 1094 km from its source in the Krkonose Mountains in the Czech Republic to the North Sea mouth at Cuxhaven, is the fourth longest river in Europe and the third longest in Germany. Its catchment area spans 148,268 km^2. The Elbe River basin is inhabited by 24.5 million people. Due to the river's altitude the catchment area is influenced by snow melting and storage processes. The Elbe River belongs to the rain-snow type; discharge behaviour is mainly influenced by winter floods and spring floods. Figure 2.2 shows the annual flood discharge peaks at the Dresden gauge between 1890 and 2002.

The last extreme flood events that the Elbe River experienced within recent decades exceeding the mean high water discharge (in Dresden: 2500 m^3s-1) took place in August 2002 and March/April 2006.

Figure 2.2: Annual flood discharge peaks at the Dresden gauge in Germany. The red coloured bars symbolize summer floods, blue bars winter floods



Source: IKSE 2005: 227

Danube River basin:

The Danube River is Europe's second largest river basin, with a total area of 801,463 km². The river basin includes the territories of 19 countries, has a length of 2,800 km, and is home to 81 million people. The source of the Danube is located in the Black Forest in Baden-Württemberg, Germany. Of Germany's territory, over 56,184 km² are drained by the Danube, and some 9.4 million inhabitants live in the area. The German Danube region is influenced by the Atlantic Climate, with an average precipitation of about 1030 mm per year, increasing from north to south. The discharge behaviour is mainly influenced by alpine snow melting in spring and large precipitation events in summer. The most recent extreme flood events in Germany took place in May 1999, 2002, and 2005.

Rhine River basin:

The Rhine River is one of the most important rivers in Europe with a length of 1,320 km, an average discharge of more than 2000 m³s-1, a catchment area of 185,000 km², and about 50 million inhabitants living in the river catchment area. It is also the longest river in Germany. It originates in the Swiss Alps, from its two main initial tributaries called the Vorderrhein and the Hinterrhein. The Rhine traverses Switzerland, Germany, France, and finally the Netherlands where it drains into the North Sea. The run-off regime of the Alpine, High, and Upper Rhine is mainly determined by nival and glacial processes, while in the Middle and Lower Rhine catchment it is determined by pluvial processes.

The most recent extreme flood events that threatened settlements and ecosystems occurred in 1993, 1995, and 1999.

Apart from the above-mentioned rivers, smaller rivers have also experienced extreme flood events recently (e.g. the Oder River in 1997 and the Loisach River in Bavaria in 2005).

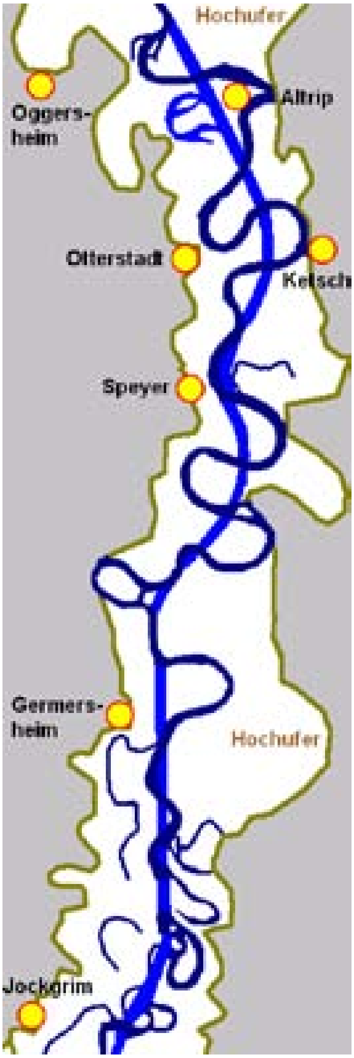
2.4 River regulations and land use

Most rivers in Germany have experienced significant transformations of their natural river channels and floodplains. During the last few centuries the straightening of rivers, the building of reservoirs, and the installation of dams and dykes have significantly affected natural processes. In the early 19th century the transformation of the Rhine was the greatest civil engineering scheme that had ever been undertaken in Europe. The rectification was supervised by Gottfried Tulla. The river was rechanneled through a system of cuts, excavations, and embankments over 354 km of its length. The multiple tributaries and deviations of the Rhine valley were marshalled into a single bed (see Figure 2.3).

The Danube is regulated along over 80 % of its length. Dyke systems have been built to prevent floods along the Danube ever since the 16th century. Only about a fifth of the traditional floodplains still remain.

In comparison to other rivers in Germany, the Elbe River is often described as a river in a quite natural state. However, it has also been considerably transformed. Along the Middle Elbe for example, 730 km of river embankments and 500 km of backwater embankments reduced 76 % (3285 km²) of the traditional inundation areas and 2.3 billion m³ of the retention volume (IKSE 2005: 26).

Figure 2.3: Rhine rectification



Source: Giel 2005

To avoid confusion with the term 'floodplain' this dissertation uses the expression 'inundation area' to describe the area between a river and a dyke, and 'floodplain' for the area that can possibly be flooded when dykes are breached or overtopped. Germany's floodplains are intensively used by humans. Today, Germany's

Figure 2.4: Map of Germany. In light orange are the federal states which joined the Federal Republic of Germany in 1990

Source: Author

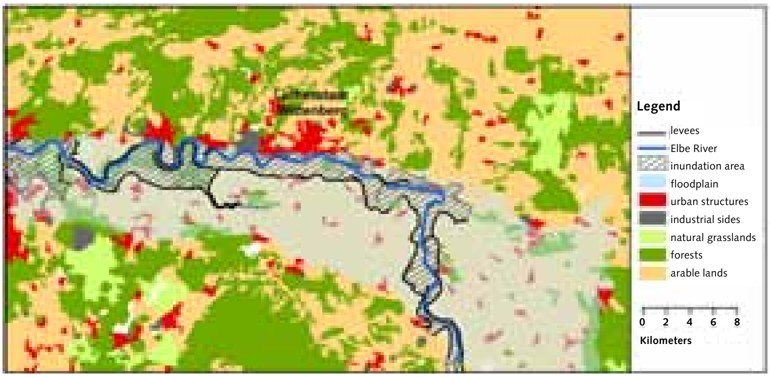
floodplains are intensively used by humans. Today the main land use is dedicated to agricultural purposes. Hence, pastures, crops, and fruit plantations have taken over large areas of the floodplains.

The natural land cover is floodplain forest. However, forests have been reduced, significantly during the last few centuries. This has been due to structural changes of the river system, conversion to other land use forms such as arable lands, and conversion to economically used forest plantations that do not correspond to traditional floodplain tree species and forest types.

Nevertheless, a rethinking process is obviously going on in Germany. More and more natural conservation areas are created in floodplains. Sustainable use is strongly promoted and dykes are partially relocated backwards in order to create more space for the rivers.

Figure 2.5 shows a stretch of the Elbe River in Saxony-Anhalt with the town 'Lutherstadt Wittenberg' in the centre. This stretch is a typical example of land use in Germany's inundation areas and floodplains. It is obvious that today's inundation areas (dashed area) comprise only a small area of former floodplains (light blue area). Agricultural land use dominates the picture. Moreover, many settlements are located in the floodplain, but are mostly protected by levees.

Figure 2.5: Land use in the Elbe floodplains



Source: Author

In conclusion, Germany is a highly developed country which has intervened in its river systems for centuries. The consequences are densely populated and intensively used floodplains which are prone to extreme floods or the failure of dykes and other protection measures.

3. Theoretical and conceptual framework

Social-ecological vulnerability with regard to natural hazards is a developing and complex field of research which has evolved from a diversity of concepts and theories. Studies on SES and on vulnerability have only recently started to be linked with each other (see Adger 2006). To establish a sound theoretical and conceptual framework it is necessary to (1) review theories and concepts of social-ecological systems and vulnerability, (2) identify working definitions and concepts, and (3) link both concepts to a framework that facilitates the assessment of social-ecological vulnerability.

3.1 Vulnerability in the context of disaster and hazard research

The initial birth of hazard and disaster research in geography is attributed to Harlan Barrows and his presentation of "geography as human ecology" (Barrows 1923). Employing the human ecological approach, Barrows and his students dwelled on the study of how people and society adjust to environmental extremes, most notably floods. Until the 1970s, the traditional natural-hazard approach dominated the scientific community, but criticism of the narrowness of the theory arose. The opinion that disasters are not just produced by physical events, but also include socially constructed situations, spread in disaster research. As a consequence, today, disaster research addresses not only the hazard side, but also deals intensively with the notion of vulnerability (Cannon 1993; Schneiderbauer and Ehrlich 2004). In an overview article about the state of disaster studies Alexander (1997) asserted that the "emergence of the notion of vulnerability is one of the most salient achievements in the field during recent decades". The emphasis on vulnerability is associated with a shift from seeing a disaster as an event caused by an external agent to a more sociologically oriented interpretation of disaster as a complex process that is socially, politically, environmentally, and economically constructed (Frerks and Bender 2004). This shift of thinking has important implications for the manner in which disasters are managed. "Attempts to control the environment need to be replaced by approaches that emphasize ways of dealing with unexpected events and that stress flexibility, adaptability, resilience and capacity" (Bankoff et al. 2004: 4).

Vulnerability research examines causal structures, spatial variability, and methods for disaster reduction. Broadly defined, "vulnerability is the potential for loss of property or life from environmental hazards" (Cutter et al. 2000: 715). However, there are many competing and contradictory definitions of the concept, as pointed out elsewhere (Cutter 1996; Thywissen 2006). In the final document of the World Conference on Disaster Reduction, the Hyogo Framework for Action 2005-2015 underlined the need to promote strategic and systematic approaches to reducing vulnerabilities and risks to hazards. The declaration in the document points out that "the starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge" (United Nations 2005: 7).

Accordingly, the concept of vulnerability has recently been gaining ground in the disaster risk community. Recognizing the fact that vulnerability is an important concept for the detection and mitigation of disaster risks, a large variety of concepts and approaches have been developed from different research disciplines. The next sections give a brief introduction to the distinct approaches and concepts of vulnerability. Traditional concepts as well as modern streams of vulnerability research are presented.

3.1.1 Traditional vulnerability approaches

The evolution of vulnerability concepts in recent decades has been influenced by different epistemological orientations (human ecology, social science, spatial analysis), their subsequent methodological practices, variations in the choice of hazards (flood, famine, drought) and by the analysed regions (developing versus industrial countries).

Several scholars have reviewed the evolution of vulnerability concepts and found different concepts and themes of vulnerability. For instance, Cutter et al. (2003) proposed the differentiation as (1) vulnerability as exposure, (2) vulnerability as social condition, and (3) vulnerability as the integration of potential exposures and societal resilience with a specific focus on places (Cutter et al. 2003). The first research theme examines the source of biophysical or technological hazards. The studies are characterized by a focus on the distribution of a hazardous condition, the human occupancy of this hazardous zone, and the degree of loss (Burton et al. 1993; Quarantelli 1992). The second group focuses on coping responses, including societal resistance and resilience to hazards. The nature of a hazardous event is usually viewed as a social construct rooted in historical, cultural social, and economic processes, not as a biophysical condition. (Blaikie et al. 1994; Chambers 1989; Watts and Bohle 1993). The third direction combines elements of the two and integrates biophysical and social vulnerability but within a specific area or geographic domain. Recently, a number of researchers have used this integrative approach in a wide array of spatial contexts or places (Cutter et al. 2000; Kasperson et al. 1995).

Adger (2006) identifies two major research traditions as “seedbeds” for ideas that eventually translated into current research on vulnerability. These antecedents are, first, the analysis of vulnerability as lack of entitlements and, second, the analysis of vulnerability to natural hazards. “Entitlements-based explanations of vulnerability focused almost exclusively on the realm of institutions, well-being and on class, social status and gender as important variables, while vulnerability research on natural hazards developed an integral knowledge of environmental risks with human response drawing on geographical and psychological perspectives in addition to social parameters of risk” (Adger 2006). While the entitlements approach often underplayed ecological or physical components, it succeeded in highlighting social differentiation in the cause and outcome of vulnerability. By contrast, the second research tradition on natural hazards, attempts to incorporate physical, engineering, and social science to explain linkages between system elements.

Vulnerability approaches can also be differentiated in, on the one hand, concepts that are created to facilitate applied research by focusing on the main elements and processes and, on the other hand, concepts that seek to contextualize vulnerability by embedding it in certain theoretical and conceptual structures.

Three vulnerability models are mentioned here that have significantly contributed to the discussion on vulnerability in the last two decades. One is the 'Pressure-and-Release Model' (PAR) developed by Blaikie et al. (1994) which originates from the physical hazard tradition defining risk as the product of hazard and vulnerability. It presents an explanatory model of vulnerability that involves global root causes, regional pressures, and local vulnerable conditions depicting the progression of vulnerability. The PAR model synthesizes social and physical vulnerability and gives equal weight to hazard and vulnerability as pressures. However, it fails to provide a systematic view of the mechanisms and processes of vulnerability.

"Sustainable livelihoods and poverty research are shown as a successor to vulnerability as entitlement failure" (Adger 2006: 272). A sustainable livelihood refers to the well-being of a person or household, and comprises the capabilities, assets, and activities that lead to well-being (Chambers and Conway 1992; DFID 1999). While livelihoods are conceptualized through capital assets including natural capital, the physical and ecological dynamics of risk remain largely unaccounted for in this area of research. The 'livelihood framework' is often applied in vulnerability assessments at local scale concerning the issue of poverty (e.g. Black 1994; Korf 2004; Pryer 2003). This framework encompasses livelihood assets and their access, vulnerable context elements such as shocks, seasonality, and trends, as well as institutional structures and processes (Birkmann 2006a).

Another well-known vulnerability model is called the 'Double Structure of Vulnerability' by Bohle (2001). This concept depicts external and internal sides of vulnerability. The internal side represents the capacities to anticipate, cope with, resist, and recover from the impact of a hazard; the external side involves exposure to risks and shocks. Vulnerability is clearly defined as a potentially detrimental social response to external events and changes. Exposure encompasses features related to the entitlement theory and human ecology perspectives. This model is the only one that explicitly mentions various theories in which the concept of vulnerability is embedded. However, it is more conceptual and does not facilitate the assessment of vulnerability in a practical way.

3.1.2 Recent trends in vulnerability research

Apart from the traditional concepts and vulnerability models which are still being used, refined, and further developed by the vulnerability community, new trends in vulnerability conceptualization can be observed. Of course, the antecedent research traditions still strongly influence new concepts, methods, and ideas. Nevertheless, holistic and dynamic vulnerability concepts that capture not only the multiple dimensions of vulnerability (environmental, social, economic) but also the temporal, spatial and temporal dynamics are on the rise. Moreover, system-oriented research is emerging, which attempts to understand vulnerability in an integrative manner in the context of social-ecological systems (Adger 2006). Finally, the concept of resilience is increasingly entering the vulnerability discussion from an ecological perspective.

For instance, multi-dimensionality vulnerability embedded in a dynamic feedback loop model is conceptualized in the BBC Model which builds on the conceptual work done by Bogardi and Birkmann (2004) and Cardona (1999, 2001). It underlines the need to view vulnerability within a dynamic process, integrates vulnerability in the hazard-risk context, and sees vulnerability as directly linked to the social, environmental, and economic dimensions. An intervention system is delineated that is understood as a measure to reduce vulnerability and risk to the consequences of a hazard of natural origin. The BBC model represents a conceptual advance in analysis, and also provides an analytical background for applied vulnerability research. However, it does not emphasize the coupled bounded social-ecological (or human-environment[6]) system.

This is done in the conceptual model published by Turner and colleagues (2003a). The 'Turner' model portrays vulnerability as a property of a social-ecological system, seeking to elaborate the mechanisms and processes in a coupled manner on a particular spatial scale. Vulnerability in this framework is composed of the three components 'exposure', 'sensitivity', and 'resilience'. The model presents very well the interlinkages and components in a coupled system. However, the diverging interpretations and definitions of the notions of sensitivity and resilience weaken the model significantly.

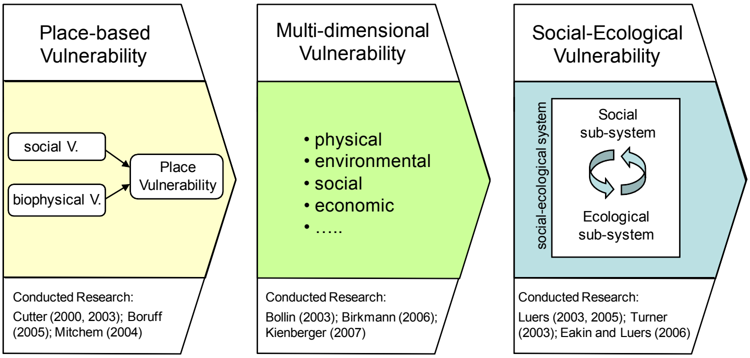
Timmerman (1981) was among the first to bring resilience theory to the social sciences, arguing that the vulnerability of a society to hazards is a product of rigidity resulting from the evolution of science, technology, and social organization (Eakin and Luers 2006). Originating from ecological research (Holling 1973), resilience contributed to the exchange of ideas about assessing and understanding vulnerability broadly in relation to a variety of stresses and shocks acting on and within coupled social-ecological systems. Although it is widely recognized that the characteristics of resilience generally match the ideas of the vulnerability concept, there is a discourse going on about whether resilience can be regarded as a component of vulnerability or whether it should be seen as a concept independent of vulnerability. Nevertheless, it is undeniable that social-ecological resilience is an important subject that should be considered thoroughly with respect to the conceptualization of social-ecological vulnerability.

The evolution of integrative vulnerability concepts and frameworks combining social and biophysical components of vulnerability in one approach and aiming at the assessment of vulnerability is illustrated in figure 3.1. It becomes obvious that the trend goes from a dualistic view that distinguishes between biophysical and social vulnerability, towards a multi-dimensional view trying to incorporate multiple dimensions in one approach, and then towards the attempt to synthesize different aspects of vulnerability and work with coupled social-ecological systems in a vulnerability framework. Social-ecological vulnerability does not claim to be a completely new concept, but clearly builds on the ideas and findings of the antecedent concepts.

---

[6] A variety of equivalents exist in literature. For example: human-environment, human-nature, socio-ecological, etc.

Figure 3.1: Trend analysis of vulnerability concepts



Source: Author

3.1.3 Why social-ecological vulnerability?

This dissertation is engaged in the assessment of social-ecological vulnerability, and is thus following the current trend of conducting integrative vulnerability research. As it is the aim of this study to concentrate primarily on non-urban landscapes in Germany, the environmental component is, of course, dominant. However, it is not only the natural sphere which is affected by river flooding. As already outlined in chapter 1.2, floodplains are SESs where human and natural spheres are strongly interlinked. This means that a social component has to be included in order to capture the complete picture of the vulnerability of the SES at a particular place and time.

Nevertheless, it has to be clearly stated that social-ecological vulnerability is still a very new concept, and only a few applied approaches can be found in literature (Eakin and Luers 2006; Luers 2005; Luers et al. 2003; Turner et al. 2003b). Moreover, it is an approach that requires the establishment of clear definitions and careful choice of terminology to avoid confusion. System-oriented vulnerability assessments must additionally consider complex interactions and a variety of elements and processes. And finally, boundaries and scales of analysis have to be defined and conceptualized thoroughly as well.

3.2 ‘Nature’ and ‘Society’ – a concept of mutuality

Social-ecological vulnerability is conceptually located at the “intersection of nature and culture, and demonstrates the mutuality of each in the constitution of the other” (Oliver-Smith 2004: 11). Thus social and physical scientists are likewise addressed. Hence, it is not surprising that different schools of thought exist defining both spheres either in a very dualistic or mutual way, from an anthropocentric or biocentric perspective.

Oliver-Smith (2004) briefly outlines the historical development of the construction of nature and society. Whereas in the medieval period, nature was commonly conceived to be "in partnership" with humanity, in the 17th and 18th centuries the utilitarian perspective dominated, seeing humans as distinct from nature. Nature was regarded as an object external to humanity that could be dominated and formed by humans. In the 20th and 21st century different concepts and theories developed with regard to the dualistic entities of nature and society. "Although there is a general agreement that both entities are heavily interwoven and have to be understood in a mutual way, there is still the tendency to express the relationship in dualistic terms" (Oliver-Smith 2004: 14).

The concept of 'nature' and society' in this dissertation is based on the ideas and concept of Becker and Jahn (2006). Social ecology is a new research discipline in Germany which aims to enhance theoretical and problem-oriented research on social-ecological systems. It is developed in the tradition of human ecology which has been a discipline unique to Germany since the 1970s and has similar research subjects and objectives. Social ecology according to Becker is defined as a "science of societal relations to nature"[7] (Becker and Jahn 2006). The concept of society and nature as well as their mutual interrelations and influences is the main topic of this discipline. In comparison to human ecology there are some essential differences in the understanding of 'nature' and society' which are outlined in the following.

The concept of human ecology has mainly developed from ecological principles and ecosystem theory which are embedded in anthropological research. Human ecology understands society, also called the social system, as an integral part of nature. "The social system is everything about people, their population and the psychology and social organization that shape their behavior" (Marten 2001: 1). "The ecosystem is composed of a set of components which act in combination within the system and which can be divided into classes of abiotic and biotic components" (Schutkowski 2006: 18). Just like any biotic component of an ecosystem, humans are tied into structural and functional relations with living organisms and the inanimate environment. Humans have the ability to interfere with, steer, and change interrelations with their environments through cultural and social systems. They respond to the given conditions of the habitat or ecosystem they live in, but they are also able to alter these conditions by changing their environment. Schutkowski (2006) sees culture as a property of human ecosystems. Since humans are subject to the same ecological principles as other components of the ecosystem they can be examined from the viewpoint of system theory.

By contrast, social ecology according to Becker and Jahn (2006) sees humans not only as an integral part of nature or a "creature of nature", but as a species that lives in both the society and in nature. Humans are not only organisms but are "creatures of culture"[8] (Becker and Jahn 2006). Thus, society and nature are still considered as two independent entities. Yet, the differentiation is more methodologically driven. Social ecology recognizes that the two realms cannot

---

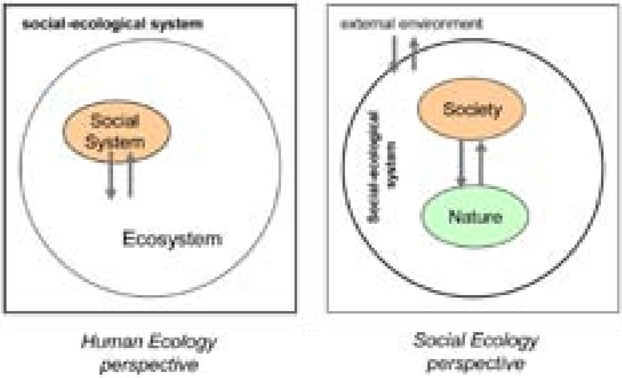
[7] German: Wissenschaft der gesellschaftlichen Naturverhältnisse

[8] German: Kulturwesen

be separated, as society has transformed and domesticated nature and both are therefore heavily intertwined with each other. Hence, society and nature are not separated ontologically, but are differentiated methodologically in two different fields of research. However, it must be pointed out that this school does not understand society and nature in a dualistic way. Traditional dualism sees the two entities as mutually exclusive with an irreconcilable gap between them (Ritsert 1995). As social ecology wants to investigate the relationships between nature and society, the mutuality of both entities is a prerequisite. Both disciplines use different terms to set up their concept of humans and nature. Whereas human ecology usually speaks of 'social systems' and 'ecosystems', social ecology uses the expressions 'nature' and 'society'.

Figure 3.2 delineates the different conceptual understanding of the key elements ecosystem/nature and social system/society as they are perceived by the author. On the left side, the traditional human ecology perspective is presented showing the social system as an integral part of the ecosystem. Hence, an analysis of the social-ecological system considers the ecosystem as such at a certain place. On the right side the two interacting entities society and nature are depicted. However, they are defined as two single and different entities. Both entities are part of the social-ecological system which is influenced and interacts with the external environment. Gallopin (2003) presents similar alternative systemic representations of social-ecological systems, but without assigning them to a particular research discipline.

Figure 3.2: Two conceptual models of 'society' and 'nature' stemming from the human ecology and social ecology perspectives



Source: Author

Despite some conceptual differences, the theoretical closeness between both disciplines cannot be denied. First, both seek to learn more about the relationships between society and nature; second, system-oriented research is an integral part of the concept; and third, in both disciplines substantial efforts are made to develop integrated approaches on social-ecological systems (Berkes et al. 2003). Both disciplines recognize the high complexity of social-ecological systems as being responsible for the production of new patterns and structures from the interaction between the social and the ecological system. These so-called 'emergent phenomena' can only be described and identified through knowledge of internal system interactions and processes.

3.3 Important terms to be defined associated with Social-Ecological Systems

A SES is defined as "a system that includes societal (human) and ecological (biophysical) subsystems in mutual interactions" (Gallopín 2006: 294). A SES can be specified for any scale. For instance, Schellnhuber (1998) labelled the SES at the global scale as the "Earth System", whereas this dissertation works with districts at regional scale.

Instead of using 'society' as a key term for the theoretical concept as proposed in Becker and Jahn (2006), the term 'social system', or even more detailed, 'social subsystem', is used to characterize everything in relation to humans. This means societal processes, institutions, as well as all economic, demographic, and cultural features in a society. Social systems exist at various functional (e.g. local, federal, national authorities) and spatial levels (household, community, state). The expression 'social system' is selected for this study, since it directly indicates the systemic context of SES[9].

The ecological system (or subsystem) is characterized by biotic (excluding humans) and abiotic components interacting with each other. The ecological system is understood as an umbrella term for all different types of ecosystem at the place of analysis. The notion of 'nature' is substituted by ecological system in this study as 'nature' is used in a controversial manner in literature. Additionally, ecological system underlines the systemic character of this term.

The notion of 'environment'[10] has manifold and diverse meanings in literature. In particular, in German literature it is often used as an equivalent for 'nature', or at least refers to the biophysical sphere. However, the 'environment' can also relate to the social milieu that influences individuals, groups, or event societies. Very often, 'environment' is used to describe nature which is defined through human influence, use, and overwhelming presence.

Becker and Jahn (2006) point out that 'environment' is a relational term. An objective definition is not possible as individuals, societies, or groups are defined through and related to different specific environments. Thus, they have discarded 'environment' from the list of theoretical key terms in their concept. In this study, 'environment' is only used in a theoretical system context referring to the external environment of a social-ecological system.

---

[9] This definition must not be mistaken for Luhmann's definition of a 'social system' which presents social systems as systems of communication, and society as the most encompassing social system. Luhmann 1984.

[10] German: Umwelt

According to Christopherson (1996), "an ecosystem is a natural unit consisting of all plants, animals, and micro-organisms (biotic factors) in an area functioning together with all of the non-living physical (abiotic) factors". This definition excludes humans from being part of ecosystems and thus follows the demands of social ecology. The term 'ecosystem' will be used in this dissertation only with respect to specific ecosystems, such as forest ecosystems. It does not encompass the whole ecological system which is composed of a variety of ecosystems (forest, aquatic, agricultural).

Table 3.1 provides an overview of key terms and their respective definitions as described in this section.

3.4 Characteristics of dynamics of Social-Ecological Systems

SESs are widely recognized as complex adaptive systems (CAS) (Berkes et al. 2003; Gallopín 2003; Gunderson and Holling 2002; Holland 1995; Holling 2001; Levin 1999). The evolution of the concept of complex adaptive systems can be traced back to a variety of theories and concepts ranging from general system theory (von Bertalanffy 1968), cybernetics (Wiener 1948), hierarchy theory (Simon 1974), to complexity theory (Holland 1995; Kauffman 1993; Levin 1999). In order to understand the characteristics and dynamics of complex adaptive systems, as well as these systems' inherent vulnerability, it is essential to learn more about the theories that CAS are based on.

Table 3.1: Key terms and definitions related to Social-Ecological Systems

Key terms	Definition
Social-ecological system	A SES includes societal (human) and ecological (biophysical) sub-systems in mutual interaction (Gallopín 1994, 2006). SESs exist at various spatial scales.
Social system	A social system includes all that is human (Gallopín 2003). This ranges from the individual to the society, from institutions to societal processes and decisions.
Ecological system	The ecological system encompasses all different types of ecosystems at a particular place of analysis. It is characterized by biotic (excluding humans) and abiotic components interacting with each other.
Ecosystem	An ecosystem is a natural unit consisting of all plants, animals and micro-organisms (biotic factors) in an area functioning together with all of the non-living physical (abiotic) factors (Christopherson 1996).
Environment	The environment refers only to the external environment.

Source: Author

3.4.1 Complexity theory

Complexity theory, or complexity research, owes much to the general systems theory as it refers also to anti-reductionism and a holistic appreciation of system interconnectedness. The general systems theory of Bertalanffy (1968) is concerned with the exploration of open systems, and the understanding of the components and their mutual interrelations. It emphasizes connectedness, context, and feedback, which is also a key concept originating from cybernetics science. It mainly refers to the result of any behaviour that may reinforce (positive feedback) or modify (negative feedback) subsequent behaviour. "With the science of complexity a new understanding of systems is emerging to augment general systems theory" (Berkes et al. 2003: 5).

In comparison to the traditional systems theory, complexity research often concerns non-linear relationships, employs techniques to examine qualitative characteristics such as the symbolic content of communication, and is concerned with how complex behaviour evolves or emerges from relatively simple local interactions between system components over time. Complexity research claims that complex systems self-organize in emergent phenomena that cannot be understood without reference to sub-component relationships (O'Sullivan 2004). An example of an emergent feature within SESs is the existence of inherent system vulnerability caused by the huge variety of system properties and interactions. Complex systems have the ability to remember and learn through the persistence of internal structures (Holland 1995). In summary, complexity research is concerned with how systems change and evolve over time due to the interaction of their constituent parts (Manson 2001).

3.4.2 Hierarchy theory and Panarchy

Simon (1974) was one of the first to describe the adaptive significance of hierarchical structures. He called them 'hierarchies', but not in the sense of a top-down sequence of authoritative control. Rather, semi-autonomous levels are formed from the interactions among a set of variables that share similar speeds and spatial attributes. The smaller levels communicate information or material to the next higher level. As long as the transfer from one level to the other is maintained, the interactions within the levels themselves can be transformed, or the variables changed, without the whole system losing its integrity (Holling 2001). Ecologists applied the term 'hierarchy' to ecological systems. In particular, Allen and Starr (1982) and O'Neill et al. (1986) stimulated a major expansion of discussion on a multi-scale view. They recognized that biotic and abiotic processes could develop mutually re-enforcing relationships over distinct ranges of scale. Levin (1999) expanded the representation of cross-scale dynamics in a way that greatly deepened the understanding of the self-organized features of ecosystems.

"Scale is important in dealing with complex adaptive systems" (Berkes et al. 2003: 6). Social as well as ecological systems may be constituted hierarchically as a nested set of systems from the local level through regional and national and so forth. Phenomena at each level of scale tend to have their own emergent properties, and different levels may be coupled through feedback relationships

(Gunderson and Holling 2002). Therefore, complex systems should be analysed or managed simultaneously at different levels. In Gunderson and Holling (2002) the concept of ‘Panarchy’ is presented. Panarchy is a hierarchical structure in which systems such as SESs are interlinked in never-ending adaptive cycles of exploitation (r), conservation (K), release (Ω), and reorganization (α). These cycles are nested within one another across space and time scales, as shown in figure 3.3.

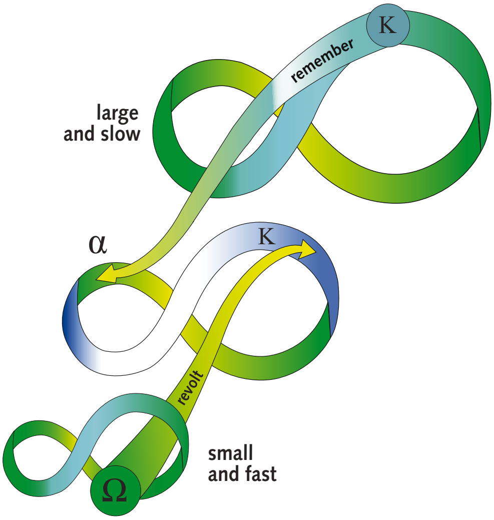
3.4.3 Complex adaptive systems and resilience

CASs are special cases of complex systems. They are complex in that they are diverse and made up of multiple interconnected elements, and adaptive in that they have the capacity to change and learn from experience[11].

SESs are CAS because “they are comprised of heterogeneous components whose actions combine to produce emergent behavior that creates results that are often unexpected” (Bennett and McGinnis 2008: 843).

Interactions, feedback mechanisms, self-organization, emergent behaviour, non-linearity, cross-scale relationships, path dependency, and adaptability are key characteristics of complex-adaptive systems (Bennett and McGinnis 2008; Holland 1995; Levin 1999; Manson 2001; O’Sullivan 2004). Detailed definitions can be found in Bennett and McGinnis (2008).

Figure 3.3: Panarchy, a heuristic model of nested adaptive renewal cycles emphasizing cross-scale interplay



Source: Folke 2006. Modified version from Gunderson and Holling 2002

---

[11] The term ‘complex adaptive system’ was coined at the interdisciplinary Santa Fe Institute (http://www.santafe.edu/) in Santa Fee, USA.

A consequence of path-dependency[12] is the existence of multiple basins of attraction in ecosystem development and the potential for threshold behaviour and qualitative shifts in system dynamics under changing environmental influences (Levin 1998). Since the publication by Holling (1973) of multiple basins of attraction in ecology, numerous scholars have reviewed regime shifts between alternate states (e.g. Folke et al. 2004; Scheffer et al. 2001; Walker et al. 2004). These reviews show that shifts between states in ecosystems are increasingly a consequence of human actions that cause erosion of resilience (Folke 2006; Gunderson 2000). As a consequence, ecosystem states have shifted to less desirable ones with subsequent impacts on livelihood and societal development. 'Less desirable' refers to their capacity to sustain natural resources and provide ecosystem services for societal development (Daily 1997). The conclusion is that those pressures make SESs more vulnerable to changes that previously could be absorbed.

The notion of 'resilience' has experienced impressive development over recent decades. From the original meaning of "spring back into shape" or "withstand and recover quickly" (Oxford Dictionary) a whole concept has been developed. The concept of resilience emerged from one branch of ecology in the 1960-1970s (see Holling 1973) and has advanced in relation to the dynamic development of complex adaptive system (Folke 2006: 258). Today, resilience is also applied to social systems (Adger 2000; Carpenter et al. 2001; Gunderson and Holling 2002); however, it is often interlinked with the notion of adaptation or adaptive capacity. Adaptive processes that relate to the capacity to tolerate and deal with change emerge out of the system's self-organization and are the result of the acceptance of something we cannot change but are ready to live with. Hence, the concept of resilience in relation to SESs incorporates the idea of adaptation, learning, and self-organization in addition to the general ability to resist disturbance. According to Carpenter (2001), social-ecological resilience is interpreted as:

(1) the amount of change a system can undergo and still retain the same controls on structure and function

(2) the degree to which the system is capable of self-organization

(3) the degree to which the system can build the capacity to learn and adapt.

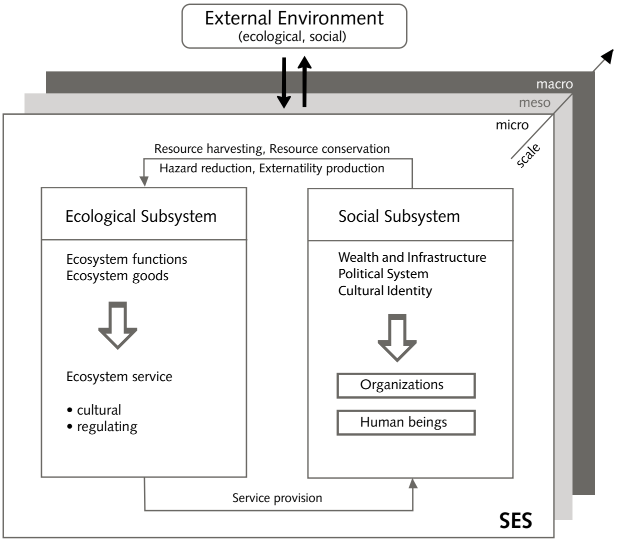
Reviews on the evolution of the concept of resilience and its application in science can be found in Folke (2006), Carpenter (2001), and Berkes et al. (2003).

Resilience has obviously developed to become a scientific field in its own right. However, as Bogardi (2009) states in his last lecture, the original meaning of resilience refers to the capacity to 'spring back', to 'rebound' or to recover the original shape after deformation. However, today, dozens of publications use it to account for all of our capacities, whereas it is only one of them. "It does not contribute to ease interdisciplinary discussions […]" (Bogardi 2009: 13).

---

[12] Path dependency means that today's decisions limit future opportunities (historic matters) (Bennett and McGinnis 2008).

Figure 3.4: Key elements, characteristics, and interactions within a Social-Ecological System



Source: Modified from Chapin et al. 2006

3.4.4 Processes and interlinkages in Social Ecological Systems

SESs and their inherent system complexity require a detailed understanding of characteristics and dynamics. The previous paragraphs have attempted to give an overview of key properties, terminology, and construction of a SES. Figure 3.4 illustrates the key elements and processes within a social-ecological system. The ecological subsystem is defined by its ecosystem functions and services. The categories of ecosystem services developed by the Millennium Ecosystem Assessment (MEA 2003) are used in this study. The ecosystem services most readily incorporated into the social system are the goods (provisioning services) that are directly harvested and used by human beings (e.g. crop, timber, water). Additionally, there are supporting services (basic ecological functions that shape the structure and dynamics of ecosystems); regulating services such as weather and flood regulations that augment the spatial scale of social-ecological interactions from individual stands to landscapes; and cultural services that provide a sense of place and identity, aesthetic or spiritual benefits, and opportunities for recreation and tourism. The social subsystem, however, is defined by economic, political, and cultural characteristics that constitute a society and define human existence at a particular place. Various hierarchical elements are interconnected by cross-scale interactions ranging from national (predominant culture, governance system) to local (community, social groups).

According to Chapin et al. (2006), the best way to describe interactions between both subsystems is through the analysis of institutions. They identified at least four types of institution that differ in their ecological goals and consequences: (1) resource-harvest institutions that are responsible for the way people manage the supply and harvest of ecosystem goods; (2) resource-conservation institutions that govern choices to conserve and protect ecosystem services; (3) hazard-reduction institutions that steer actions to reduce the societal impacts of natural hazards such as floods; and finally (4) externality-production institutions exist which are "a heterogeneous suite of rule sets that, in the process of pursuing social and economic development goals, have unintended side effects on ecosystems, creating externalities. These institutions include policies affecting credit and interest rates, international trade, war, […]" etc. (Chapin et al. 2006: 16639).

The described institutions directly influence ecosystem services. However, choices made and actions undertaken by those institutions also indirectly cause feedbacks to the social system itself through the quantity and quality of service provision.

3.5 Transformation, regime shifts, and vulnerability

It is important to differentiate between transformation, on the one hand, and regime shifts from one state to another on the other. The various domains that a system may occupy, and the boundaries that separate them, are known as a "stability landscape" (Walker et al. 2004). Whereas transformation refers to the development of a new stability landscape which requires structural changes of the whole setting, the shift to a new state (or domain of attraction) occurs within one stability landscape.

Transformation is often taken to mean harm or damage to a system (Gallopín 2006). However, transformation is in general understood as the capacity to create new stability landscapes by introducing or bringing out new variables, or by losing existing variables of a system. Both exogenous drivers (e.g. floods) and endogenous processes (plant succession, management practices) can lead to changes in the stability landscape. Examples are: changes in the number of domains of attraction, changes in the positions of the domains, changes in the positions of the edges (or tipping point) between domains, or changes in the 'depths' of domains (resistance) (Walker et al. 2004).

It is problematic when SESs are unable to transform or shift to another state. For example, in floodplains, the construction of dams and dykes intervene in natural adaptive processes, and moreover, allow humans to feel safe, which might prevent them from undertaking any adaptive measures. Only the building of risk awareness and the provision of a scope of action opens the opportunity of transformation. Hence, transformation is considered as something positive in this study. The less capacity for transformation exists in a SES, the more vulnerable it becomes.

Walker et al. (2004) uses the term "precariousness" to describe how close the current state of the system is to the edge/tipping point. To determine the degree of vulnerability in a system it is necessary to understand where the system is located within the domain of attraction.

In summary, the assessment of vulnerability of a SES requires information about the following important aspects:

- What is a favourable and what is an unfavourable state?
- What is the current state of a SES?
- What is the current precariousness of the system within its domain of attraction?

3.6 The concept of space

As we have already noted, SESs are regarded as open systems that are in constant exchange with their environment. However, the mapping of social-ecological vulnerability across regions requires the use of certain units of analysis that are characterized by finite boundaries. Prior to the translation of interactions and dynamics of a specific SES to the selected unit of analysis, the relevant types of scales and levels have to be identified.

This section explores the challenges and implications that are related to the scale issue, and to selecting an appropriate unit of analysis.

3.6.1 Terminology related to scales

First of all, it is necessary to introduce a common vocabulary and set of working definitions of scale-related terms, as the word 'scale' is used in many contexts and often connotes different aspects of space and time. Following Fekete et al. (2009), this dissertation uses the key terms as defined in table 3.2.

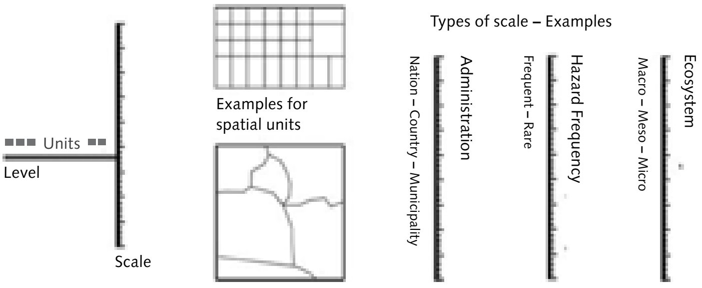
Table 3.2: Definitions of key terms related to scale used in this dissertation

Key terms	Definition
Scale	The vertical axis along which any objects of interest are ranked.
Research area	Total area/extent of observation.
Level	A fixed rank or horizontal layer on a scale.
Unit	Homogeneous spatial entities like pixels, or administrative boundaries.

Source: Author

Figure 3.5 illustrates visually the differences between level, unit, and scale, and additionally shows some examples of typical scale types. Recognizing that scales also cover temporal and functional dimensions, this section is devoted to spatial scales only.

Figure 3.5: Visual interpretation of the used working definitions and presentation of typical types of scale

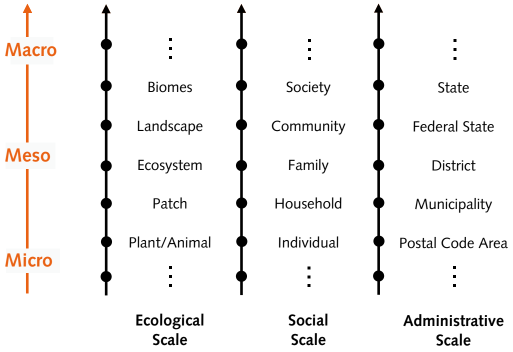


Source: Fekete et al. 2009

Identification of relevant spatial scales:

To capture the vulnerability of the SES, different types of scales have to be considered: a scale representing the ecological subsystem, a scale representing the social subsystem, and if necessary, an additional scale that contains the level of analysis. Figure 3.6 shows the distinct types of scales and respective levels that could be identified as relevant in the presented study. The ecological scale ranges from single plants or animals to the existence of biomes; the social scale ranges from individual human beings to societies in a country; and the administrative scale ranges from postal code areas to the state. Whereas the social and ecological scales explain phenomena that exist in the social and ecological systems, the administrative scale was identified as very useful for the later selection of a unit of analysis.

Figure 3.6: Ecological, social, and administrative scale



Source: Author

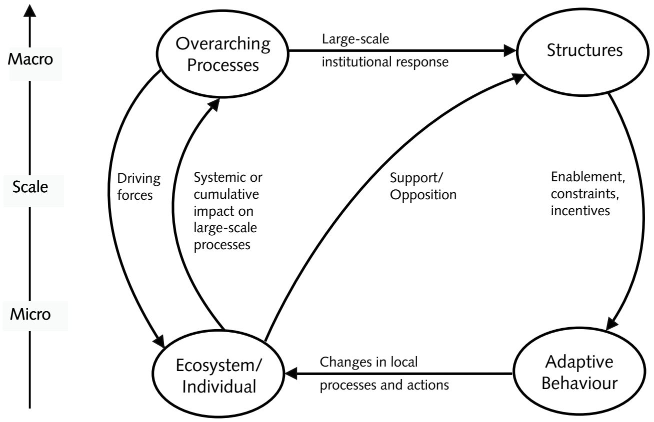
Cross-scale and cross-level interactions:

"Interactions may occur within or across scales, leading to substantial complexity in dynamics" (Cash et al. 2006: 9). Cross-level interactions refer to interactions among levels along a scale, whereas cross-scale means interactions across different scales. However, the challenges which emerge from capturing those interactions are manifold. First, there is the high complexity of system dynamics, which aggravates the detection of cross-scale/level interactions. Second, scale mismatches have to be expected between the ecological and social scales with regard to decisions, actions, transboundary issues etc. (see Cash and Moser 2000; Cumming and Collier 2005; Folke et al. 2007; Gibson et al. 2000). Finally, the failure to recognize heterogeneity in the way that scales are perceived and valued by different actors also hampers cross-scale analysis.

Macro scale and micro scale processes and phenomena interact across levels in ways such as those shown in figure 3.7. For instance, local actions shaped by larger driving forces add up to impacts on large-scale processes. Institutional responses on larger scales, shaped by democratic support or opposition from smaller scales, lead to large-scale structures that enable (or constrain) local-scale adaptive behaviour.

Cross-scale interactions can be observed, for instance, when land use management imposed by human beings impacts single ecosystems or even whole landscapes. All changes in the ecological system feed back to the social system and trigger an institutional response.

Figure 3.7: Cross-level and inter-level interactions at micro, meso, and macro level in the social-ecological system



Source: Adapted from AAG 2003

Implications of the unit of analysis:

The appropriate choice of a unit of analysis is crucial for the ongoing research. The selection influences conceptual as well as methodological decisions that have to be made in this context. The Millennium Ecosystem Assessment can be cited herewith: "The choice of scale is not politically neutral, because the selection may intentionally or unintentionally privilege certain groups. The adoption of a particular unit of analysis limits the types of problems that can be addressed, the modes of explanations that are allowed, and the generalizations that are likely to be used in analysis" (MEA 2003: 122). Various approaches have been suggested by scholars for how to identify the most appropriate scale for an assessment. The options range from trying to minimize statistical errors between observed and modelled phenomena to weighing increased information from finer spatial resolution against the difficulties of gathering and analysing the information (Wilbanks 2002). Moreover, a scale can also be selected on the basis of empirical evidence about the process involved (Kasperson et al. 1995), and because of its correspondence to human decision-making (Cash and Moser 2000).

Further examples of how the unit selection influences the approach can be found in Fekete et al. (2009). The unit of analysis is mainly responsible for the type of data to be collected, and the subsequent treatment of this data. For instance, if an administrative level (e.g. district) is selected, each unit has a different size, which has to be considered in later calculations. A grid cell, on the other hand, would guarantee equal size for each unit of analysis. Another important aspect is the end-user who is addressed by the approach. When selecting a unit of analysis it is necessary to be aware of the needs and demands of potential recipients and users.

Up- and downscaling effects:

Another important effect of dealing with different types of scales and with the matter of cross-level analysis is the fact that all data has to be converted to one specific level. The consequence is that up- and downscaling processes must be carried out. However, some problems arise from this. These problems are mainly provoked by false assumptions due to generalization when data is up-scaled, and simplification when data is down-scaled. These problems have been intensively discussed among scientists (see e.g. Cao and Lam 1997; Openshaw 1984; Wu and Li 2006). Solutions for down- or upscaling are well documented in statistics (Jeffers 1988) and GIS/Remote Sensing literature (Wu and Li 2006). The MEA (2003) suggests categorizing variables into scale-dependent, scale-independent, and non scalable types.

3.6.2 Selection of a unit of analysis

According to Gibson et al. (2000) and Wilbanks and Kates (1999), the spatial unit of analysis needs to be congruent with the purpose of the assessment. In this dissertation the research area and unit of analysis were identified according to the objective of this research in order to develop a tool that enables the detection of vulnerability at a broader scale and that is applicable to all of Germany.

After careful research on available data sources, and discussions with potential stakeholders and end-users the decision was made to use the administrative level ‘district’ (German: Kreis) and the correspondent urban level ‘independent cities’ (German: kreisfreie Städte) as units of analysis in this research. This level was selected for several reasons: a) districts are relatively homogeneous in size in comparison to municipalities and postal code areas, b) disaster management as well as many other political processes are organized and supervised at the district level, c) the objective to provide an overview of regional patterns with regard to large-scale flood events can be provided best at district level, d) a sufficient number of variables is available from federal statistical data, e) districts correspond to the designated European administrative unit NUTS3, enabling the transfer of the approach to other European countries, and f) the administrative level district is readily understood by decision-makers.

Hence, a sub-national vulnerability approach is used which enables the comparison of regions across Germany. The district level is a compromise between the aim of generating an overview for the whole country and the fact that data for all of Germany is only available at this level. A sufficient amount of available data allows assessment of vulnerability for any county so that in principle, the whole of Germany can be covered. Districts represent an intermediate level on the administrative scale, which facilitates the integration of data from lower and higher levels. This also creates the possibility of validating the results with vulnerability maps generated at a lower level, as was done by O’Brien et al. (2004b) for instance.

3.6.3 The agricultural and forest sectors

This dissertation is dedicated to the assessment of vulnerability, addressing the SESs. SESs have been defined and characterized in the previous sections. However, with regard to the large extent and complexity of social-ecological systems, it is appropriate to specify the SES to be addressed in this research.

A sectoral approach (see Villagrán de Léon 2006) was selected to create more transparency and facilitate the detection of SES components and interrelations. The approach of employing sectors was originally proposed from the policy point of view because it promotes the assignation of responsibilities to certain public or private organizations.

The two sectors of ‘agriculture’ and ‘forest’ will be investigated in this study, since these sectors face significant consequences when river flooding occurs.

Forest sector:

According to figure 3.4, the forest sector can be considered as SES. The ecological subsystem is composed of numerous forest ecosystems that provide supporting services (e.g. primary production and CO_2 sequestration), provisioning services (e.g. timber and fuel), regulating services (e.g. potentially erosion control, climate regulation), and cultural services (recreation, education). The social subsystem strongly benefits from those services, so that large-scale disturbances in the ecological subsystem often have major adverse impacts. Forest ecosystems are almost completely managed in Germany, meaning natural forests hardly exist anymore. Whether they are intensively harvested or carefully conserved and rebuilt, interventions are strong. Therefore, both subsystems are directly interlinked.

Agricultural sector:

Even more obvious are the interlinkages with the agricultural sector, where anthropogenic ecosystems have been generated with the purpose of providing humans with food, fibres, and fuel. Even though the provisioning services might be considered as the most important ones, agricultural ecosystems can also contribute with several of supporting (nutrient cycling), regulating (erosion control, disease control) and cultural (customs and traditions) services to human well-being. Any major disturbance such as flooding might affect the livelihood of single households, or even the economy of a region. The way arable lands are harvested and managed or hazard management is conducted, depends on the social system's characteristics.

In conclusion, the two sectors 'forest' and 'agriculture' are addressed in this research as SESs and will be analysed with respect to their vulnerability to river flooding. Mapping of vulnerability will be carried out at district level for the whole of Germany. Not only forested areas and arable lands in potential floodplains will be addressed, but also the related sectors for each district.

3.7 Designing a vulnerability framework

To achieve the major aims of this study it is necessary to develop a conceptual framework that facilitates the assessment and mapping of vulnerability. The framework has to meet the demand of providing guidance for scientists, of being conceptually sound, and of facilitating the operationalization of assessing vulnerability.

3.7.1 Important elements and aspects

The previous sections have provided an overview of theories and concepts that mainly influence the way social-ecological vulnerability has to be addressed and defined. From what we have learned so far about SESs, CASs, their dynamics and characteristics, it becomes apparent which aspects ought to be considered in the proposed conceptual framework.

a) As the social-ecological vulnerability is addressed here, the vulnerability framework should clearly identify the SES as the subject of analysis. This implies that a systemic view is presented by the framework. Moreover, key system elements have to be consistently included, since vulnerability is linked to system qualities or elements, each of which must be understood in order to address vulnerability.

b) The framework should clearly name the components of vulnerability. Due to diverse existing definitions and constituents of vulnerability, it is crucial to define those components and their properties in the vulnerability framework.

c) A place-based analysis enables a better understanding of characteristics and processes within specific suites of stresses and the emergence of vulnerabilities in particular SESs. It is assumed that anchoring SESs in particular places facilitates the understanding of the generic and the specific, along with comparisons among the place-based systems. The place of analysis in this case is the district level, and comparisons are made across Germany.

d) The vulnerability of a system is the product of multiple stresses and perturbations emanating from both the social and ecological subsystem. Since cumulating stresses can enhance, or alternatively, reduce resulting levels of stress on a system, it is important to consider multiple perturbations and their interactions. It has to be recognized that internal and external stresses can put pressure on the SES. Thus, internal perturbations can arise from, for example, diseases or land degradation. External perturbations are, for example, caused by floods in areas where inundation is not part of the ecological system.

e) SESs are subject to influences that operate and interact spatially, functionally, and temporally across a range of nested or overlapping scales and levels. Therefore, it is not sufficient to focus on dynamics and processes at the place of analysis, but to look at influencing factors and drivers beyond the place.

f) Vulnerability is not a static dimension of a system but varies in response to the changing character of the system itself. The dynamic behaviour of vulnerability in an SES has to be indicated by integrating feedback loops and interlinkages between the system components.

g) Incorporating a causal structure that delineates the specific forms of the processes that build vulnerability is desirable as well. The identification of this causal structure is a central theme of assessing vulnerability.

3.7.2 Proposed vulnerability framework

The vulnerability framework which is used in this research is adapted from a framework published by Turner and colleagues (2003a). It meets the demands of integrating the aspects and elements mentioned in the previous section. However, some modifications have been made in order to adapt it to the approach used.

Presentation of the proposed framework:

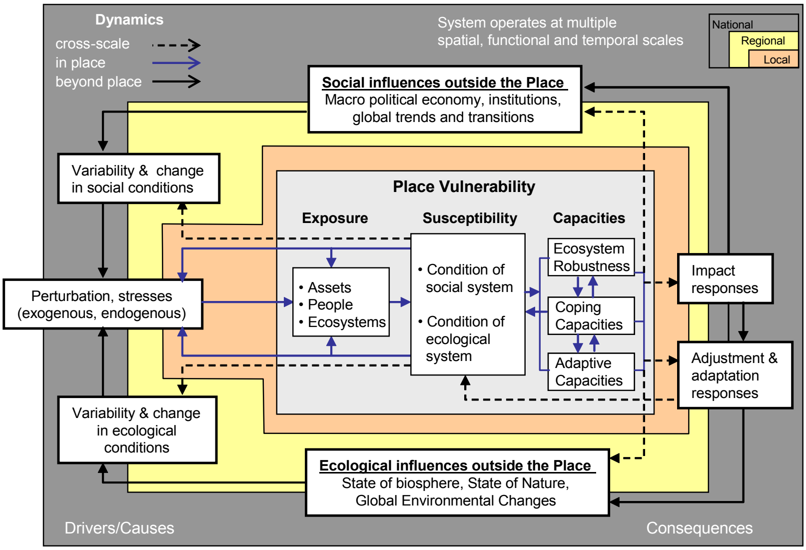
The conceptual framework (see Figure 3.8) presents a systemic approach considering the SES[13] as the subject of analysis. It views vulnerability as related to a certain place that is constituted of several place-internal processes as well as cross-scale ecological and social influences. The place of analysis can be at any scale in the system. Vulnerability is composed of three main elements: exposure, susceptibility, and capacities. Elements exposed to a hazard can be human beings, assets, ecosystems, etc. Susceptibility indicates the condition or rate of response of the SES with regard to all perturbations and stresses within the system. Capacities define the ability of a system to resist, cope with, and adapt to a certain hazard. The interactions of perturbations are also reflected in the framework. However, it is important to distinguish conceptually between (1) internal perturbations that

---

[13] Turner et al. (2003a) use the expression ‘human-environment system’ instead of SES.

determine the current condition in SESs and thus the vulnerability at a particular place and time, and (2) external perturbations that strike a system, provoking disturbance and damage. Although the framework contains numerous interlinkages and feedbacks, vulnerability is still understood as being processed in a causal structure. The left side of the graphic represents the drivers and causes, whereas the right side considers the consequences. Vulnerability is a dynamic feature that changes over time and place.

Figure 3.8: Vulnerability framework used in this study



Source: Modified from Turner et al. 2003a

Modifications:

The modifications made in the conceptual model in comparison to the version published in Turner et al. (2003a) either refer to the nomenclature in the framework or are of a conceptual nature. The changes have been made in order to adapt the framework to the needs and theoretical concepts of this study or in order to consistently apply the introduced vocabulary of the previous sections. The modifications are briefly explained in the following.

According to the concept of social ecology, this research sees a SES as embedded in its external environment. As already mentioned, perturbations can emerge from the external environment, in terms of a natural hazard for instance, as well as from the SES itself in terms of, for example, land use changes. The traditional framework only emphasized the existence and interactions of internal stresses and perturbations as determinant factors of vulnerability. As this research investigates vulnerability to an external hazard, this aspect must also be described. This is done by the text box 'perturbations and stresses' which is part of the SES as well as the external environment.

The original 'resilience' component in the Turner framework was substituted by the term 'capacities'. This is to avoid confusion with the concept of resilience which has recently been developed and widely discussed in the scientific community (see Chapter 3.4.3) and, moreover, has nothing to do with the original connotation of resilience. The author considers 'resilience' as an independent concept and not necessarily as an integral part of vulnerability.

The sub-component 'impact response' was excluded from the framework as well. As vulnerability to flooding is supposed to be analysed in this study it is the potential vulnerability of an SES that is of interest – before the next flood event strikes. Therefore, the impact response of any disturbance is ignored, even though it is acknowledged that vulnerability is an inherent dynamic property of a SES that exists during all temporal intervals of a flood event.

'Ecosystem robustness', on the other hand, was added to the 'capacities' component to create a sub-component which is solely dedicated to the behaviour of the ecological subsystem. This is particularly important, since this research addresses the sectors of agriculture and forest. The sub-components 'adaptive' and 'coping capacities' are only concerned with the response of the social subsystem.

Turner et al. (2003a) follow a place-based approach and emphasize the importance of considering the cross-scale dynamics in every vulnerability analysis. The traditional framework depicts 'place' as the lowest level on the spatial scale, where regional and global interactions have certain influences. However, this can be very restrictive, as there is always a lower level that influences a system's vulnerability. Place vulnerability can be analysed at any level along the spatial scale though. In this research, the sub-national level 'district' is determined as a unit of analysis which is considered as a meso or regional level approach. Hence, place vulnerability is still labelled to indicate that a place-based approach is to be conducted.

Constraints of the framework:

Although the framework is only a very simplified reflection of real system dynamics, the proposed model can be regarded as quite complex in terms of operationalization. Based on the version presented by Turner et al. (2003a), only a few attempts have been made to implement the framework. In Turner et al. (2003b) three case studies are presented that use the Turner Model as a conceptual framework. The paper concludes as follows: "[…] this general conceptual framework provides a useful point of departure for examining vulnerability. For practical and theoretical reasons, such frameworks should be modified (simplified) to suit the specifics of a given application" (Turner et al. 2003b: 8085). Thus, a major challenge of this research is the operationalization of the conceptual vulnerability framework according to Turner et al. (2003a).

A second constraint of the framework is the missing notion of risk. The concepts of risk and vulnerability are very often strongly interlinked in disaster research (see, for example, the BBC Model or Bollin et al. (2003)). The proposed framework does not establish any relationship however, and hence, does not outline how risk is conceptualized in this research. In chapter 3.8, this gap will be filled by elaborating on the topic of risk and vulnerability.

3.7.3 Defining the important elements of the vulnerability concept

The vulnerability framework contains the three main components of exposure, susceptibility, and capacities. Since many contradictory meanings of these terms exist, this section will provide more detailed information to create a better understanding.

Social-ecological vulnerability:

Vulnerability is an inherent property of each SES. The expression 'social-ecological vulnerability' is therefore regarded as equivalent to 'vulnerability of a social-ecological system'. Social-ecological vulnerability is composed of the exposure, susceptibility, and capacity of elements at risk in a SES. It determines "the degree to which a system, subsystem, or system component is likely to experience harm […]" (Turner et al. 2003a: 8074). Furthermore, "vulnerability changes over time and is driven by physical, social, economic, and environmental factors" (Thywissen 2006).

Exposure:

The vulnerability component 'exposure' determines the degree to which a SES is exposed to a specific threat or perturbation. In this dissertation, exposure has to capture elements from the ecological and social subsystem concerned with the sectors of forest and agriculture that might be exposed to flooding. These can be forested or agricultural sites as well as, for example, employees working in the respective sectors.

Exposure is seen as the starting point in a vulnerability analysis. Unless there are exposed elements, no vulnerability can be detected ($E = 0 \Rightarrow V = 0$).

Exposure can be understood and measured in two different ways. In the first case it is directly linked to the perturbation/hazard and is calculated by the extent to which the element of risk is exposed to a hazard (here: floods). This is, for example, the percentage of arable lands possibly flooded during a flood event. In the second case, exposure is not directly linked to the hazard but refers only to the elements of risk and their existence in a certain unit of analysis. An example is the percentage of forested area per district.

There is an intensive debate going on in the scientific community about when to speak of exposure, and whether it can be considered a component of vulnerability at all. However, in the end it is mostly the research approach that determines the way exposure is defined and measured. In this research, exposure is understood as described in the second example. This is especially due to the fact that vulnerability is considered as a generic intrinsic feature of the SES which is, in the first instance, not dependent on any flood extent but composed of the system's own characteristics. Hence, exposure is independent of any hazard characteristic.

Susceptibility:

Susceptibility is the vulnerability component that describes the current state of the SES's elements. According to Turner et al. (2003a), it is mainly defined by cross-scale interactions of multiple internal stresses and perturbations. In other words susceptibility is a measure to determine the rate of deterioration within a domain of attraction. The more sensitive a SES is, the more reduced is its precariousness (see Chapter 3.5). This means that a shift to a more unfavourable domain of attraction is very possible because the edge of the domain (or tipping point) is close. The susceptibility emerges from stresses in the ecological or social subsystem. Perturbations in the ecological subsystem can be contamination or pre-damage; in the social subsystem, economic stress or political insecurity might impose additional stress on the system. Of course, susceptibility is a dynamic element and changes continuously over time.

Capacities:

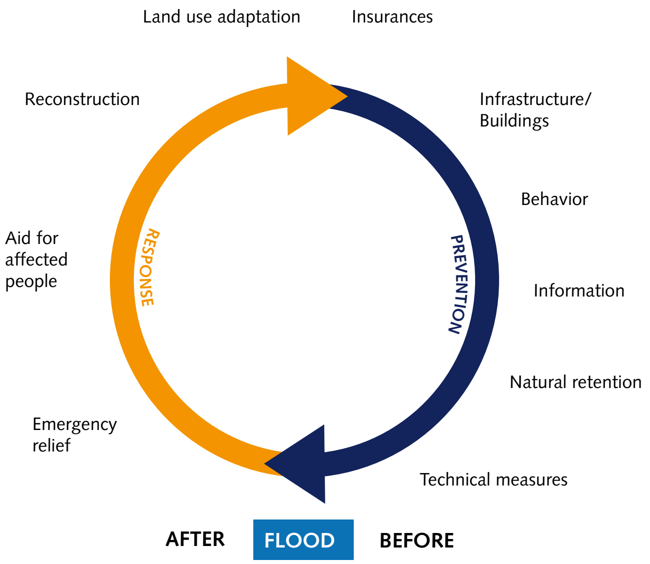
Capacities represent the combination of all strengths and resources available in the SES. They reduce the overall level of vulnerability and thus the effects of a striking hazard. The vulnerability component 'capacities' is composed of the three sub-components 'ecosystem robustness', 'coping capacity' and 'adaptive capacity'.

In this research, ecosystem robustness addresses the capacity of the ecological system to absorb and resist disturbance while re-organizing and undergoing change. However, the main functions, structure, identity, and feedbacks may essentially be retained (Gunderson 2000). "The concept of robustness is well developed in engineering science where it refers to the maintenance of system performance […]" (Anderies et al. 2004: 1).

Coping capacities are the means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster (UN/ISDR 2004). Coping capacities are needed during the occurrence of a natural hazard. The term refers to operational flood management, which is one of the two main pillars of disaster management in Germany (DKKV 2003). Operational flood protection means all available disaster response measures such as evacuation plans, early warning systems, management plans, etc.

Adaptive capacity is the sub-component that reflects the learning aspect of system behaviour in response to disturbance (Gunderson 2000). In this research the existence of different precautionary measures is seen as crucial for building adaptive capacities. Precaution (German: Vorsorge) is the second pillar within flood disaster management. According to DKKV (2003), several types of precautionary measure exist, which are spatial planning and land use management, maintenance of information and awareness, financial resources, construction measures, and technical protection measures (see Figure 3.9).

Figure 3.9: Disaster cycle



Source: Modified from DKKV 2003

Hazard:

The term 'hazard' has already been used several times without its meaning being explained in detail. In general, a hazard is defined as an "act or phenomenon that has the potential to produce harm or other consequences to a certain element" (Multihazard Mitigation Council 2002). When speaking of a hazard this study refers to any external perturbations that emerge from outside the SES. Natural hazards in particular are natural processes or events that may constitute a damaging event (UNDP 2004), such as floods or storms. 'Hazard' is a common expression in risk and vulnerability research and is usually used to characterize the properties of the damaging event itself. By contrast, vulnerability is concerned with the properties of the SES and its components. One may argue that flooding is a natural process in the SES floodplain and should thus not be considered as external. However, this research is particularly concerned with the consequences of 'extreme' natural hazards at a regional level. This means that large areas are affected that are usually protected against flooding. In those areas, river floods are not part of the ecological system.

Any internal system perturbations and stresses can also be viewed as hazards according to the definition above. Nevertheless, in order to avoid confusion, this research distinguishes between internal and external hazards by using ‘perturbations’ for internal and ‘hazard’ for external stresses.

3.8 Risk and vulnerability

The purpose of any vulnerability assessment is to gain insights into the weaknesses of a system/element at risk and thus to contribute to the reduction of risk. Therefore, the concept of vulnerability is usually linked directly to risk. Hence, a comprehensive conceptual framework has to define the relationship between both concepts. Usually, mathematical equations have been used to explain these relationships.

Most dictionaries define ‘risk’ as the “possibility of loss or injury” (Merriam-Webster 2003) or “the chance of something bad happening” (Cambridge Dictionary 2000). The definition of risk has many different nuances, but most of them have one in common: the notion of probability that something negative will happen. However, risk is more than a simple expression; it is a concept which is used in various research disciplines. Risk denotes a potential negative impact to an asset or some characteristic of value that may arise from some present process or future event.

Risk as defined in this dissertation does not consider the probability of a flood event. In comparison to the engineering approach that usually calculates risk from the probability of an event and the losses it produces, this study sees risk as the possibility that adverse consequences may occur depending on the different characteristics of the natural hazard and social-ecological vulnerability. Probability does not refer to the hazard itself but to the adverse impact that might happen. This is why the mathematical equation used here differs from the traditional engineering one. The equation that is used to define risk is:

$$R = f\ (H,V) \tag{1}$$

where H stands for Hazard and V for Vulnerability. Hence, risk is a function of hazard and vulnerability. This definition is not new in the disaster risk community, but is found in various scholarly works (e.g. Blaikie et al. 1994; Bollin et al. 2003; Maskrey 1989) and application (UNDP 2004).

Vulnerability is defined by E (Exposure), S (Susceptibility), and C (Capacities).

$$V = g\ (E,S)\ -C\ ) \tag{2}$$

3.9 Working definitions at a glance

In the previous chapters a framework was developed with the aim of facilitating the assessment of social-ecological vulnerability. A set of working definitions that is used throughout this dissertation is provided in table 3.3.

Table 3.3: Working definitions in this research

Important component	Definition
Risk	Risk denotes the possibility of a potential adverse impact to a system or system components that may arise from some present process or future event.
Vulnerability	Vulnerability is an inherent property of each SES and determines the degree to which a system, subsystem or system component is likely to experience harm (Turner et al. 2003a). Vulnerability changes over time and is driven by physical, social, economic and environmental factors." (Thywissen 2006).
Hazard	An act or a phenomenon that has the potential to produce harm or other consequences to a certain element. (after Multihazard Mitigation Council 2002).
Natural Hazard	Natural processes or phenomena occurring […] that may constitute a damaging event. (UNDP, 2004) Examples: Flood, earthquake.
Exposure	"Elements at risk […] that are exposed to a hazard." (UNDP 2004).
Capacities	Capacities are defined by the combination of all strengths and resources available in the SES that reduce the overall level of vulnerability and thus the effects of a striking hazard.
Ecosystem robustness	Ecosystem robustness describes the capacity of a ecological system to absorb and resist disturbance while re-organizing and undergoing change.
Coping capacity	The means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster. (UN/ISDR 2004).
Adapting capacity	Adaptive capacities refer to a longer time frame and imply that some learning either before or after an extreme event is happening.

Source: Author

3.10 Intermediate conclusion and outlook

Assessing vulnerability is a complex and challenging task and requires the establishment of a clear theoretical and conceptual framework. This chapter has completed this task by (1) providing an overview of the concepts of vulnerability, social-ecological systems, space and risk, (2) by elaborating on the essential elements that have to be captured for the assessment of social-ecological vulnerability, and finally by developing an appropriate framework. The conceptual vulnerability framework is very important as it serves as the basis for all the following conceptual and operational decisions.

4. Indicators as measurement tools

4.1 General information on indicators

Given the complexity of SESs, the assessment of vulnerability requires a reduction of potentially available data to a set of important indicators and criteria that facilitate an estimation of vulnerability. The final document of the World Conference on Disaster Reduction, the Hyogo Framework for Action 2005-2015, stresses the need to "develop systems of indicators of disaster risk and vulnerability at national and sub-national scales that will enable decision-makers to assess the impact of disasters […]" (UN/ISDR 2005: 7). Indicators are widely recognized as useful measurement tools in distinct fields of research, and are considered to highlight trends and conditions for policy purposes. The basic premise of indicators is that through a limited set of figures, social-ecological issues can be effectively communicated, conditions monitored, and results of policy and management can be measured. Indicators are at the interface of science and politics. Hence, to be effective, indicators must be credible (scientifically valid), legitimate in the eyes of users and stakeholders, and salient or relevant to decision makers (Moldan and Dahl 2007; Niemeyer 2002).

Developing and using indicators is not a new field of research. Economic indicators emerged in the early 1940s. Today, economic indicators such as GDP or unemployment rate as well as very sophisticated indices such as the Human Development Index (HDI) are widely used to estimate and communicate the state and evolution of the economy. Since the 1970s, social indicators have conquered the social sciences. The development of environmental indicators also started in the 1970s, linked to the establishment of environmental policies (Birkmann 2006a). Finally, indicators gained importance in the area of sustainable development. Various approaches to define and operationalize sustainable development with indicators can be found in literature (e.g. Esty et al. 2005; Hák et al. 2007). In Germany, indicators are often used in spatial and regional planning. Every few years, the Federal Office for Building and Regional Planning (BBR) publishes a report on spatial development and spatial planning in Germany using indicators to analyse and visualize demographic, social, economic, and environmental issues. Traditionally, most indicators for decision makers have been numbers calculated by statistical services, including complex indices such as GDP or percentages such as unemployment rate.

Such values have various functions, but the most important is to transform raw data into information. Even though, in principle, the essential function of indicators is to quantify, indicators may be either a qualitative (nominal) variable, a rank (ordinal) variable, or a quantitative (interval) variable. Qualitative variables may be preferable to quantitative indicators when quantitative information is not available, and when the attribute of interest in inherently non-quantifiable (Gallopín 1997).

"Indicators necessarily limit themselves to the sphere of the measurable" (Moldan and Dahl 2007: 9). Like models, indicators can reflect reality only imperfectly. However, even within the measurable, the quality of indicators is determined largely by the way reality is translated into measures and data, be they quantitative or qualitative. Although present scientific knowledge does not claim to understand all aspects of social-ecological interactions and feedback loops between the subsystems, many issues are sufficiently well understood to enable the building of scientifically accurate indicators. The quality of indicators inevitably depends on the underlying data that is used to compose them. According to Moldan and Dahl (2007), the quality of indicators can be judged on five methodological dimensions: purpose and appropriateness in scale and accuracy, measurability, representation of the phenomenon concerned, reliability and feasibility, and communicability to the target audience. There is seldom a perfect indicator. Thus the design generally involves some methodological trade-offs between technical feasibility, societal usability, and systemic consistency.

4.2 Definitions

A variety of definitions is available in literature regarding indicators and indices. A selection of different definitions is provided in Table 4.1. A review of those definitions shows that it is necessary to differentiate between the terms ‘indicator’, ‘index’, and ‘composite indicator’.

This research defines indicators as the representations of a certain construct or issue that might be too complex to be captured by a specific variable (Moldan and Dahl 2007). An indicator is not the real attribute of a real object, but an image or abstraction of the attribute. A variable, by contrast, is raw data that lacks any symbolic representation and reference value such as benchmarks. More complex multi-dimensional constructs require the aggregation of several indicators. Vulnerability is such a complex construct that can only be represented by a so-called composite indicator. The peak of the pyramid (see Figure 4.1) is symbolized by the ‘index’, which represents the densest state of information as it is the product of a function. It generally takes the form of a single dimensionless number. Indices usually require the transformation of data measured in different units to produce a single number.

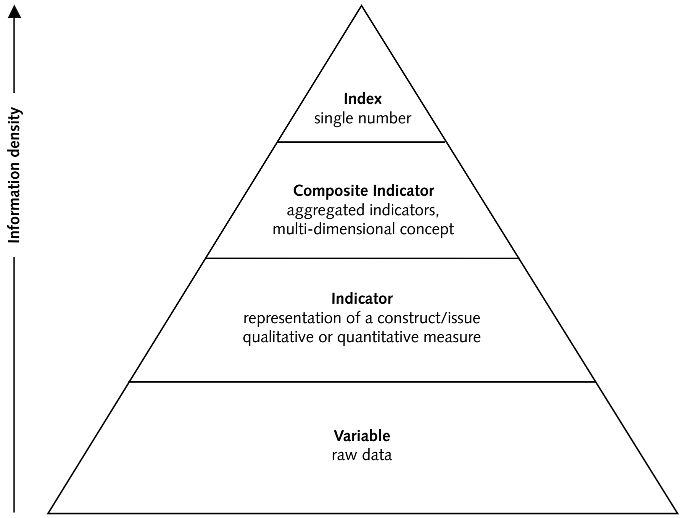
Transferring the given explanations to the present study, different indicators form a composite indicator that represents vulnerability. The index is the number produced by the calculations and representing the degree of vulnerability. How closely the variable reflects a certain issue, and how meaningful and relevant for decision-making is the chosen attribute, is a question related to the expertise and insight of the investigator, as well as to the purpose and constraints of the investigation. The significance of the variable lies in the way it is interpreted.

Table 4.1: Some definitions of 'indicators' and related terms

Source	Definition
Hammond et al. 1995:, Vincent 2004	Indicators are quantifiable constructs that provide information either on matters of wider significance than that which is actually measured, or on a process or trend that otherwise might not be apparent. Essentially they are a means of encapsulating a complex reality in a single construct.
Gallopín 1997	Indicators are variables which is an operational representation of an attribute of a system.
Moldan and Dahl 2007	An index is a single number which is a simple function of two or more variables, usually a weighted summation of individual variables.
Sullivan et al. 2002	Indicators are symbolic representations designed to communicate a property or trend in a complex system or entity. Indicators are often distinguished from raw data and statistics in that they contain reference values such as benchmarks, thresholds, and targets.
Birkmann et al. 2006a: 57	An index number is a measure of a quantity relative to a base period. Indices are a statistical concept, providing an indirect way of measuring a given quantity or state allowing comparison over time. The main point of an index, however, is to quantify something which cannot be measured directly, and to measure changes.
King and MacGregor 2000	A variable which is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of albeit an ill-defined event linked with a hazard of natural origin. An indicator can be a single variable or a sophisticated aggregated measure that describes a system or process.
Nardo et al. 2005	Indicators are simply tools that can be used to define or point to a more significant issue. They may be developed from either primary (e.g. questionnaires) or secondary (e.g. Census) data sources. Indicators are usually used to describe constructs. Thus the construct is the research object and the indicators are tools to measure it. An indicator is a quantitative or qualitative measure derived from a series of observed facts that can reveal relative positions in a given area. An indicator can point out the direction of change across different units and through time. A composite indicator is formed when individual indicators are compiled into a single index on the basis of an underlying model. It ideally measures multi-dimensional concepts which cannot be captured by a single indicator alone.

Source: Author

Figure 4.1: Indicator pyramid



Source: Sketch based on Adriaanse 1994

4.3 Indicator functions and requirements

The usefulness of indicators is determined by their success in achieving their objectives and functions. The latter include identification and visualization of different characteristics of vulnerability, or evaluation of political strategies and monitoring of their implementation. Indicators create an understanding of factors contributing to vulnerability. According to Benson (2004), the identification and the understanding of vulnerability and its underlying factors are important goals and functions of measuring vulnerability. In the meeting of the Expert Working Group (EWG) in Kobe 2005 the following functions were identified as important: setting priorities, background for action, awareness-raising, trend analysis, empowerment. More traditional functions are simplification, comparison of places and situations, assessing conditions and trends, providing early warning information, and anticipation of future conditions and trends (Gallopín 1997).

Policymakers face the difficult challenge of deciding future directions in the social, economic, and environmental realm of politics. Improving the basis for sound decision-making, and integrating many complex issues while providing simple signals that a busy decision maker can understand, is a high priority. Information tools are needed that condense and digest information for rapid assimilation while making it possible to explore issues further as needed. Moldan and Dahl (2007) see that as the main goal of indicators.

In German literature (e.g. Heiland et al. 2003; LFU 2004) the following functions are usually listed:

- Analysing – identification of problematic hot spots where actions are required
- Planning – important for the establishment of agreements, rules, and action plans. Enhancement of effective planning.
- Controlling – development of trend analyses and time series enable control of the implementation of certain targets.
- Communicating – measures and plans become transparent and understandable, which facilitates the discussion between politicians and population.

Numerous selection criteria are usually applied when identifying an appropriate list of indicators. The requirements that indicators have to fulfil are manifold. A distinction can be made between standard criteria (technical considerations), participatory relevant criteria (methodological considerations), and practitioner-relevant criteria (practical considerations).

Standard criteria:

Validity/accuracy: The indicator has to give a true reflection of the issue under consideration and must be developed in a consistent analytical framework. Verifiable and scientifically acceptable data has to be defined and collected that uses standard methodologies with known accuracy and precision.

Relevance: The indicator has to clearly relate to the topic and goal of the analysis.

Reproducibility: The indicator should be reproducible within defined and acceptable limits for data collection over time and space.

Sensitivity: The indicator should respond to a broad range of conditions or perturbations within an appropriate time frame and geographic scale.

Transparency: The indicator should ideally be fully transparent.

Participatory-relevant criteria:

Understandability: An important and often neglected prerequisite for the usefulness (and acceptance) of indicators is that the users must understand them.

Easy to interpret: The interpretation of data must be simple and publicly appealing. The indicator should inform clearly about the extent of the issues represented.

Practitioner-relevant criteria:

Data availability: Data must be either available or should be obtainable through measurement.

Cost-effectiveness: Indicators are more accepted when they are simple to monitor and collect.

Policy relevance: An indicator has to monitor the key outcomes, inform on any progress, measure processes, and provide specific information.

4.4 Strengths and weaknesses

Analysing complex systems and their properties involves reducing complexity to a degree that we can understand. Simplification is an accepted part of the scientific research process and is naturally associated with difficult choices about how much to simplify and how to do it without misrepresenting reality. Thus, indicators and indices are useful for encapsulating a complex reality in simple terms and permitting comparisons across space and/or time. However, in providing useful summary information there is a danger that indicators may not accurately represent the intended condition or process.

Aggregating indicators creates even more opportunities for subjectivity and thus must be even more critically appraised. Whilst the purpose of indices is to better encapsulate a complex reality, such an undertaking is limited in several ways. By their very nature, indicators have to capture an intangible process, so it is not possible to "ground truth" them. Hence, alternative means of validation must be sought. Even with a comprehensive understanding of the conceptual and theoretical underpinnings of the processes and conditions involved, indicators can only be a snapshot in time and thus are limited in their ability to represent dynamic processes. Moreover, the method of aggregating the indicator scores does not allow for the contribution of a variable to be conditional on, or amplified by, another variable, thus there is no way of accounting for the feedbacks, non-linearities, and synergies that exist in real systems. The index is also very much contingent upon the choice of indicators at the lowest level and there is a real possibility that uninformed choices at this level can filter through and may lead to an invalid index.

A critical evaluation of the appropriate use and limitations of indices is even more imperative given the fact that they link science and policy. By summarizing and simplifying reality they are inherently useful to policymakers, but the absolute certainties required are often incompatible with the uncertainties of science. To ensure the most robust and durable results, indicators and indices are never complete. Rather, they are in a process of evolution whereby a tentative theoretical proposition is empirically tested and the results fed back into conceptual development after peer review through expert judgment. The result is a continual process of refinement so that the indicators and index have the greatest possible validity and thus utility.

Apart from the named limitations of indicators and indices there is, of course, a variety of advantages that have to be explicitly mentioned in this context. Indicators enable simplification of the very complex concept of vulnerability; they facilitate the task of mapping and comparing vulnerability across regions; they enhance communication between public and politicians, they inform the public and politicians; and they help to assess any progress achieved. More information about the pros and cons of composite indicators can be found in Nardo et al. (2005) and Briguglio (2003).

4.5 Procedures for indicator selection

Adger et al. (2004) identify two different procedures for indicator selection: the deductive approach and the inductive approach. The deductive approach involves proposing relationships derived from theory or a conceptual framework and selecting indicators on the basis of these relationships. When conducting a deductive approach it is important, first, to create an understanding of the investigated phenomenon and the processes involved; second, to identify the main processes to be included in the study; and third, to select the best possible indicators for these factors and processes. To summarize, in deductive research, a hypothesis is tested by operationalizing the concepts in the hypothesis and collecting the appropriate data to explore the relationship between the measures of these concepts. Inductive approaches involve statistical procedures to relate a large number of variables to vulnerability in order to identify the factors that are statistically significant. Hence, potentially relevant indicators are incorporated in a certain statistical model and indicators are selected on the basis of significant statistical relationships. Expert judgements or principal component analysis are common methods used to select the final indicators. "Inductive research often uses empirical generalizations, filled with empirical content and statements of empirical regularities" (Adger et al. 2004: 18).

It is characteristic of many vulnerability indicator studies that they do not belong to either a deductive or an inductive approach. Many studies base their indicator selection on a basic theoretical understanding of vulnerability, and identify categories of indicators.

Studies that closely integrate theory conceptualization and indicator selection include, for instance, a case study of Georgetown County, USA, and Vietnam (Cutter et al. 2000; Kelly and Adger 2000). An inductive approach is conducted, for example, by Fekete (forthcoming) who selects indicators by means of logistical regressions, and by Kropp et al. (2006) who use cluster analysis for a regional climate vulnerability assessment.

4.6 Review of composite vulnerability indicators

Vulnerability to hazards of environmental origin has been approached from various perspectives in recent decades. The benefits that indicators and indices provide in terms of monitoring and controlling have stimulated the development of numerous vulnerability composite indicators. However, a comparison of these composites is often hampered by the different prerequisites and requirements that each study has to face. Thus, the development of a vulnerability index depends greatly on the region of interest, scale, dimension of vulnerability, and type of natural hazard. Nevertheless, some examples are presented here to show the variety of existing indices.

The EVI was developed by the South Pacific Applied Geoscience Commission (SOPAC), and focuses on the potential for damage to the natural environment per se. The EVI uses 54 indicators for estimating the vulnerability of the environment of a country to future shocks. The EVI is reported simultaneously as a single dimensionless index, several sub-indices, and as a profile showing the results for each indicator. The EVI ranks 235 countries in terms of their environmental vulnerability (Kaly et al. 2004; Kaly et al. 2003).

A regional vulnerability index was developed in the ESPON Hazard project using four indicators to measure damage potential and coping capacity – the components of vulnerability after their definition. The approach covered 27 countries of the European Union, and it was conducted on the NUTS3 level. Vulnerability indicators were derived independently from the hazard component so that they could be related to any natural hazard of interest (ESPON 2005a; Kumpulainen 2006).

Within the ATEAM project an approach to assessing the vulnerability of ecosystems to land use changes was developed by integrating the potential impacts and adaptive capacities. Indicators and land use scenarios were used to create a model which can map vulnerability across Europe. Different types of ecosystem services were addressed with regard to their vulnerability to land use changes (ATEAM 2004b; Metzger et al. 2006).

The Prevalent Vulnerability Index (PVI) depicts predominant vulnerability conditions by measuring exposure in hazard-prone areas, socio-economic fragility, and lack of social resilience. The PVI is a composite indicator that provides a comparative measure of a country's pattern or situation. It is just one index among four which were developed in the American Indexing Programme by the Institute of Environmental Studies at the National University of Colombia – Manizales in cooperation with the Inter-American Development Bank. The approach was applied to 12 countries in Latin America and the Caribbean, and includes a total of 50 indicators (Cardona 2007; Cardona 2006).

Vulnerability and risk have been assessed at the local level by the German Gesellschaft für Technische Zusammenarbeit (GTZ) (Hahn 2003). They proposed the use of several indicators from the physical, social, economic, and environmental domain to assess vulnerability at the municipal level. The approach was tested, for example, in the municipality of Villa Canales in Guatemala in connection with earthquakes.

The presented studies differ in methodology, case study area, and scale. However, they provide a good overview of the state of the art of the building of vulnerability and risk indices. The analysis of these and other studies has contributed to the development of new methods and techniques and has helped to avoid shortcomings in the research.

5. Indicator development

5.1 Overview of the methodological approach

This chapter presents methods and techniques applied to develop indicators for the assessment of social-ecological vulnerability.

One of the most fundamental choices regarding the approach to be used is between a data-driven (inductive) or theory-driven (deductive) approach. An inductive approach needs a proxy variable for vulnerability as the benchmark against which indicators are tested. However, the paradox is that the need for vulnerability indicators exists because there is no such tangible element of vulnerability. In this research, therefore, a deductive approach is favoured, whereby use is made of the theoretical insights and conceptual framework presented in chapter 3. However, the framework is only the starting point for indicator development. Figure 5.1 illustrates the procedure which has been established in this study for the identification of appropriate indicator sets. Thus, the second step after defining the basic components and criteria by means of the vulnerability framework is the collection of in-depth information on the causes and effects of flooding on the agricultural and forest sectors. An impact analysis is carried out showing the interlinkages that exist within the two sectors. This information is very important for providing an insight into the sectors' processes. Necessary details are extracted and derived from literature and expert interviews. The next step is the development of criteria for the indicator development. Criteria are the pre-stage of indicators and roughly capture a certain idea. Subsequently, different indicator approaches that cope with similar objectives are reviewed in order to retrieve a list of prominent indicators that might also be valid for this research. Then, a pre-selection of potential indicators takes place. An indicator set is created for the forest and agricultural sectors. These indicators are tested carefully, considering their respective selection criteria, data quality, and statistical correlations. Subsequently, the final indicator set is selected.

As the major goal of this research is to 'measure' vulnerability and to map it across districts in Germany, a quantitative approach is carried out. However, the methods used to create the results are not fully quantitative. Expert interviews deliver qualitative information that is integrated in the indicator development and in the evaluation of the whole approach. Hence, a semi-quantitative approach is conducted in this research. Although expert interviews play an important role in this research, the decision was made also to use secondary data for the development of indicators. This was for the following reasons: a regional approach for the whole of Germany is used, which does not allow the exclusive collection of primary data because of the lack of manpower and time. Furthermore, the availability of information on flood events and their impacts is available as well as data to map the single indicators. Even though there would be some constraints during the data collection (see Chapter 6), Germany is in the favourable position of having a large amount of available data.

The next sections in this chapter elaborate on the different phases of the indicator development procedure illustrated in figure 5.1. However, before that, information is provided about both primary and secondary data sources which had to be collected in the course of this research.

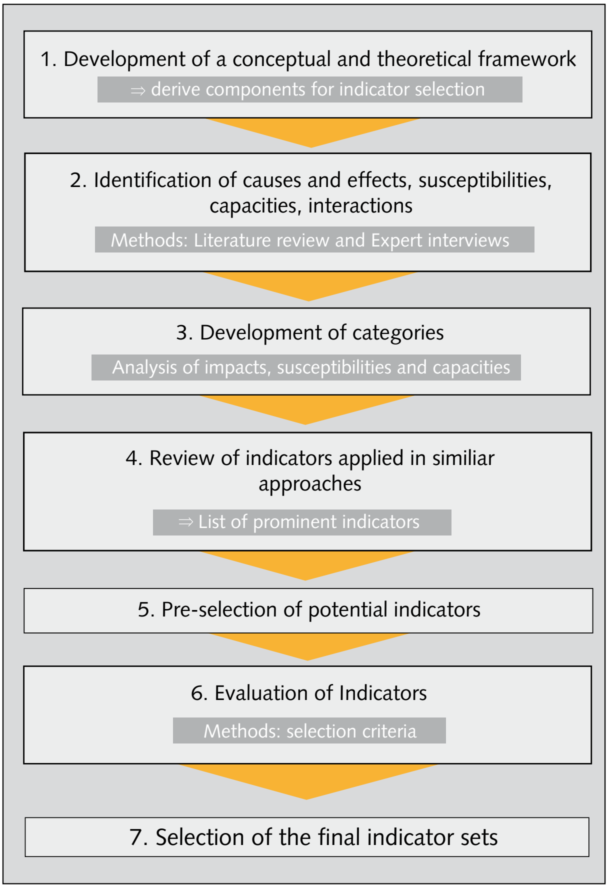
5.2 Semi-structured expert interviews

In this research semi-structured (or in-depth) expert interviews[14] were conducted to collect primary information. This section gives an overview of the technique

---

[14] in German: Leitfaden-Interview.

Figure 5.1: Procedure for the development of indicators



Source: Author

of 'expert interviews' in general, the way they were conducted in this study, and finally of the main findings that were derived from them.

5.2.1 General information

A semi-structured interview is open-ended, but follows a general script and covers a list of topics. This technique is most appropriate when you have only one opportunity to interview someone (Bernard 2006). An interview guide is indispensable as it provides a written list of questions and topics that need to be covered in a particular order. Within a certain structure the researcher is still able to formulate questions spontaneously during the interview (Kumar 1996). Hence, the advantage is that the interviewer maintains discretion to follow leads, but the interview guide is a set of clear instructions. The guide creates reliable, comparable qualitative data. The prerequisite for semi-structured interviewing is that the interviewer has to acquire more than just basic knowledge on the subject of interest in order to construct the guide and conduct the interview. Thus, substantial time and effort must be invested before the interview. Semi-structured interviews work well in projects where the interviewer has to deal with high-level bureaucrats. This method allows full control over the interview but leaves the respondent free to follow new leads (Bernard 2006).

Advantages of semi-structured interviews:

(1) The more complex the situation or topic, the more appropriate is the interview. The interviewer has the opportunity to prepare a respondent before asking sensitive questions, and to explain complex ones to respondents in person. (2) In-depth information can be obtained more easily in an interview, as the situation allows probing.

(3) An interviewer is able to supplement information obtained from responses with that gained from observation of non-verbal reactions.

(4) To avoid the misinterpretation of a question the interviewer can put the question in another form or explain it more in detail.

Disadvantages of semi-structured interviews:

(1) Interviewing is time-consuming and expensive when potential respondents are scattered over a wide geographical area.

(2) The quality of data and information is dependent upon the quality of interaction between the interviewer and interviewee.

(4) There is always the danger of introducing the researcher's bias into the framing of questions and the interpretation of responses.

According to the definition of Archer et al. (1998), an expert is an individual with access to the specialized information needed for a research. Moreover, Meuser and Nagel (2005) see an expert as a person who is responsible for the development, implementation, or control of solutions/strategies/policies. Hence, experts are representatives in so far as they represent certain decision structures. Experts in this research are defined as (1) representatives of organizations that are involved in decision-making processes (e.g. bureaucrats), (2) people that have relevant experience of the topic of interest (e.g. testimonials of flood events), and (3) people that have substantial knowledge of relevant physical processes and functions (e.g. scientists).

Interviewing experts allows the researcher to access detailed, directed, and often private or otherwise inaccessible information. Furthermore, the interviewer can learn from respondents and acquire unexpected information that can lead to truly new ways of understanding the events being studied (Archer et al. 1998).

However, a more difficult and very time-consuming task is the selection of appropriate experts. The selection is crucial as experts determine the quantity and quality of data and information. Moreover, there are difficulties of processing and comparing data, since each expert interview is unique. Although a set of central questions is addressed in each interview, the researcher may choose to add additional questions in the course of the interview. As a further constraint Archer et al. (1998) note the reactive nature of expert interviewing. The respondents are aware that their answers will be used in a research study, and this may lead them to alter the information given. What needs to be kept in mind is that expert knowledge is not neutral. Experts usually play a certain role or are part of a particular political debate. Therefore, it is also important to consider 'counter-experts' to get a differentiated insight into certain patterns or processes.

In this research, expert interviews were conducted for explorative and confirmative purposes. The explorative approach was applied in the first phase of the research to learn more about the impacts of flooding on the agricultural and forest sectors, the state of flood protection in Germany, and finally to gain a better insight into the interests of stakeholders and decision makers.

In a later stage the confirmative expert interview was conducted to verify information and data and for evaluation purposes.

5.2.2 Selection of experts

A variety of experts had to be identified in order to capture diverse points of view and obtain as much information as possible about vulnerability of the forest and agricultural sector. Experts were found according to the snowball principle. Thus the first contact person was asked to give a recommendation for a further expert and so forth. After a brief telephone interview the decision was made on whether to select the person as an expert or not. Table 5.1 shows the experts that were interviewed for the study. Different thematic realms and administrative levels were covered by experts to gain insights from all necessary perspectives. Thus, experts from the forest and agricultural sector, disaster management sector, and flood protection sector, as well as representatives from the tourist and water supply sectors were contacted.

Experts working for authorities, representatives from associations in the agricultural sector, scientists, and people employed in NGOs were interviewed. Through the diversity of respondents a complete picture of flood impacts, flood sensitivities, and flood strategies before, during, and after a flood event could be obtained. The majority of experts identified for the interviews were from national or regional authorities. They were usually selected as they had not only a local but also a regional overview of the occurrences in their area and were also potential end-users of the vulnerability maps to be produced in this study.

As a nationwide approach was used, experts from different geographical regions were selected. West Germany was represented by experts mainly originating from North Rhine-Westphalia and Rhineland-Palatine. In east Germany, experts from Saxony and Saxony-Anhalt were contacted for the provision of information.

Table 5.1: List of conducted expert interviews

Sector	Abbrev.	Date	Organization/Location	Duration
Forest	IP1	2006/08/28	State Office for Forest, NRW	60 min
	IP2	2007/05/22	Forestry Office Rheinauen, Bellheim	90 min
	IP3	2007/10/23	North-Western Office for Forest, Göttingen	60 min
	IP4	2007/10/26	State Office for Forest, Saxony-Anhalt	60 min
	IP5	2007/11/06	State Office for Administration, Saxony-Anhalt	90 min
	IP6	2006/09/13	Farmers' Association, Cologne, NRW	60 min
Agriculture	IP7	2006/10/30	FAL, Braunschweig	60 min
	IP8	2007/10/25	Department of Agriculture, University of Bonn	60 min
	IP9	2007/10/26	Department of Agriculture, University of Gießen	60 min
	IP10	2007/10/29	LLFG, Sachsen-Anhalt	60 min
	IP11	2007/11/07	ALFF, Dessau	90 min
	IP12	2007/11/09	Farmers' Asscociation, Jessen, Saxony-Anhalt	90 min
Natural Conservation	IP13	2006/06/22	NABU, Cologne	120 min
	IP14	2006/08/30	BfN, Bonn	120 min
	IP15	2007/10/22	WWF Germany	60 min
	IP16	2007/11/08	Biosphärenreservat, Magdeburg	90 min
Flood Protection and Disaster Management	IP17	2006/05/05	DLRG, Meißen	120 min
	IP18	2007/11/08	State Office for Flood Protection, Saxony-Anhalt	90 min
Tourism Water supply	IP19	2007/10/16	Tourism association, Saxony-Anhalt	60 min
	IP20	2007/08/28	OEWA, Leipzig	60 min
	IP21	2007/11/09	State Office for Environment, Saxony-Anhalt	60 min

Source: Author

As the Rhine River and Elbe River have experienced several extreme flood events in recent decades, people in these regions have substantial knowledge and experience of river floods and thus have a strong interest in the topic.

The expert interviews were conducted by telephone, especially in the explorative phase, as well as 'face-to-face'. If agreement was obtained, the interviews were recorded with a voice recorder and the recording was partially transcripted. Some experts preferred to be treated anonymously. Therefore, the interview analysis was carried out in an anonymous way to ensure equal treatment for all experts.

5.2.3 Construction of guidelines for the interview

Semi-structured interviews require an interview guide which helps to structure the interview and allows the findings to be compared with each other.

The main topics in the interviews were very similar or even the same apart from small modifications that had to be made with respect to the expertise of the interviewee and the sector of interest.

The interview guide was structured according to the following seven topics:

- The first part of the interview was dedicated to the introduction of the interviewer and respondent. The objectives and contents of the research were briefly presented and explained. This was necessary as most experts had never worked with indicators before. The interviewee was then questioned about his/her activities and responsibilities in the institute or organization.

- Subsequently, the interviewee was questioned about his/her experiences with flood events. It was important to learn whether and when the interview partner was involved in processes and decisions regarding flood events. Moreover, this was a great opportunity to collect additional information about recent flood events and their characteristics. It was also a good bridge to the next topic which dealt with flood impacts.

- The third topic addressed the impacts that had been observed by the interviewee during and after extreme flood events. The purpose of this question was to learn more about flood consequences in the forest and agricultural sectors. As it is not always recognized that these sectors are negatively affected at all by flood events, it was necessary to work out to what extent or when forest ecosystems and arable lands suffered from flooding and what that meant for the population.

- The next section was directed towards the susceptibilities of the forest and agricultural sectors. Here, the perturbations influencing the state of each sector were of particular interest to the research. Perturbations can be triggered by past events such as insect diseases or storms as well as continuous processes such as contamination caused by nearby industries that alter the natural conditions. The state of the social system is also of great importance to the analysis. Thus, the questions tried to capture this aspect as well.

- The third component of vulnerability was addressed in the next topic of the interview guide. The capacities of the forest and agricultural sectors depend on the ecological robustness as well as the adaptive and coping capacities of the social system. To develop indicators, more information about, for example, flood resistant vegetation, adaptive land management, strategies used for flood protection etc. has to be collected.

- The next topic aimed to explore the experts' opinions regarding relevant criteria and indicators for the forest or agricultural sector. The named indicators could later be cross-checked with the indicators developed and identified from literature.

- Finally, the opportunity was taken to ask the experts about available data usable for the visualization of the indicators. In Germany, data availability is very high. However, it is not easy to detect the data sources and to get access to the data itself.

5.2.4 Analysis of the interviews

The analysis of the interviews aimed to enhance knowledge and fill information gaps on the one hand, and to confirm information that had already been collected on the other hand. The analysis was structured in three parts. First, the recorded interviews were partially transcripted, selecting only the passages and information essential for the research. The transcription was then sent to the interview partners (when desired) to let them revise the interview text. Modifications were subsequently incorporated into the transcription. In the second step the different topics of the interview were analysed by elaborating the important aspects of each interview. Finally, in the last part, the main findings were summarized and conclusions derived.

5.2.5 Main findings and conclusions

Some of the main findings of the interview analysis are presented below. They deal mainly with topics 2 to 5 (see Chapter 2.5.3):

- All experts had experienced one or more extreme flood events in their career. They were able to provide useful information about the flood events themselves and the characteristics of the flood event that were responsible for damage in the agricultural and forest sectors. Their answers indicated that it is the flood duration, stream velocity and water height that influence the severity of an event. Moreover, the point of time is a crucial factor. The time of day (daytime vs. nighttime) as well as the time of year are very important factors affecting the degree of damage caused by inundations. For example, in the agricultural sector, economic damage is lower in winter, since the growing and harvest period in Germany is between spring and autumn.

- It was confirmed by the experts that the forest and agricultural sectors are severely affected by flooding. However, the focus was on extreme flooding, meaning flood events that exceed a reoccurrence interval of once in 100 years. In particular, the land behind dykes is impacted seriously when levees are breached or overtopped, as here the SES are not adapted to river flooding. Apart from the flood intensity it was confirmed that the consequences of flooding are mainly dependent on the sector's internal characteristics, such as soil properties, vegetation type, and contamination patterns.

- Potential perturbations that exert stress on the ecological subsystem mainly emerge from pre-damage caused, for example, by insect diseases, especially in forest ecosystems. Furthermore, contamination of soils was observed with concern by some experts. Water quality in the specific region is also an important factor, although the large rivers Elbe, Rhine, and Danube have achieved satisfactory water quality in the last years.

- Capacities are determined by different social and ecological factors. The experts emphasized the importance of precautionary measures which made a vital contribution, from their point of view, to the reduction of flood vulnerability and risk. Flood prevention measures are, for instance, land use changes or the development of hazard and risk maps. Another crucial aspect is the provision of financial aid during and after the flood event. Finally, some characteristics of the ecological systems were identified that constitute the degree of ecosystem robustness, for example, forest size and vegetation type.

- The experts felt the main benefits of the results of this research were, in particular, the provision of maps, indicators, and the development of methods that could facilitate an easily understandable, simple, but still sophisticated vulnerability and risk assessment. Although the concept of vulnerability was very complex and often difficult to understand for the experts, they recognized the importance of single indicators and vulnerability components as such. A regional approach is useful for authorities at federal, state, and national level.

There are at least two major conclusions that can be drawn from the expert interviews. First, the experts indirectly confirmed the importance of the main components of vulnerability as well as the concept itself. That means that it is not only flood characteristics that determine the degree of damage but also the characteristics of the SES. Disaster risk is therefore composed of hazard and vulnerability components. Additionally, the concept of vulnerability was confirmed by the experts as they agreed on the necessity of integrating different aspects in the concept such as the existence of certain stressors that influence the state of a SES as well as coping and adapting strategies of individuals and organizations that have been identified.

Second, the negative effects of river flooding on the agricultural and forest sectors were confirmed. Since various processes and interactions between and within the ecological and social subsystem are disrupted during flood events, the assessment of social-ecological vulnerability of both sectors is of major interest.

Third, it was possible to derive some valuable criteria for the indicator development from the interviews. These criteria are discussed in chapter 5.4.1.

5.3 Analysis of expert interviews and literature

In the following, the analysis of expert interviews and literature is carried out. The result is structured in three main parts: impact analysis, analysis of the susceptibility component, and analysis of the capacities component.

5.3.1 Impact analysis

This chapter is dedicated to the analysis of flood impacts on the forest and agricultural sector. Two impact chains have been developed to show the causes and consequences of flooding on both investigated sectors.

Forest sector:

The increased water volume in rivers as well as the rising groundwater level triggers various serious physical hazards. The deposition of sediments during flood conditions contributes to poor soil aeration. Additionally, tree roots might have to contend with high concentrations of toxic compounds such as alcohol and hydrogen sulfide that accumulate in waterlogged soils. Strong currents and soil particles suspended in flood waters can also erode soil from around the base of trees, exposing tree roots. Mechanical destruction is also a severe consequence of flooding. Ice floods in particular have caused immense damage in recent centuries when ice floes floated into forested areas (IP5[15]). In the winter season of 2002/2003 an ice flood struck the Elbe floodplains in Saxony and Saxony-Anhalt leaving behind numerous destroyed and damaged trees. Finally, flooding reduces the supply of oxygen to the leaves and roots and usually results in growth inhibition and injury of flooded trees. Thus, tree injury increases in proportion to the amount of crown covered by water (Iles and Gleason 1994).

Direct consequences of hazards caused by flooding are the loss of valuable trees and vegetation. Trees, shrubs, and seedlings can die immediately of suffocation or mechanical destruction or they die from the attack of secondary organisms in the months following an extreme flood event. Flood-stressed trees exhibit a wide range of symptoms including leaf chlorosis (yellowing), defoliation, reduced leaf size and shoot growth as well as crown dieback (Iles and Gleason 1994). A segregation of species was observed by IP2 in the municipality 'Leimersheim' adjacent to the Rhine River after the extreme flood event in 1999. Many flood intolerant species died and only certain flood tolerant species remained in the Rhine floodplains. Moreover, the forest fauna is directly affected by flooding when the habitats of wild animals are inundated. The mortality rate of the wildlife depends on the flood velocity and the time of occurrence. Hence, IP2 confirmed that animals are especially affected when forests are flooded during the nighttime. A loss of soil quality can be expected from siltation/sealing and scouring processes during a flood event (Bratkovich et al. 1993). The groundwater quality is also affected due to the amount of contaminants and suspended load washed in. Another aspect is the destruction of forest infrastructure and buildings. The mechanical destruction not only affects the forest ecosystem but also the man-made structures in the fo-

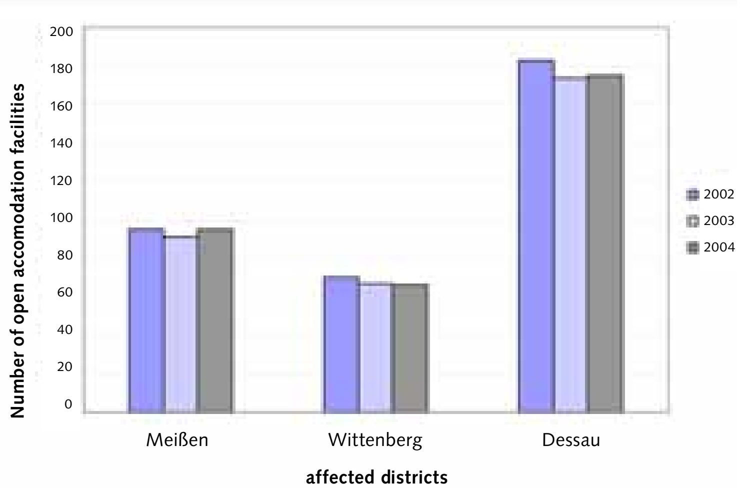
---

[15] IP5 = Interview Partner 5 (see Table 5.1).

rests. IP2 reported that many forest trails and roads could not be used anymore and had to be reconstructed. Moreover, some facilities serving educational purposes had to be rebuilt as well. After the Rhine flood in 1999 it took the forest administration at least half a year to restore the most important forest roads.

Flooding of forest ecosystems also has consequences for forest ecosystem services. In figure 5.3 some of the most seriously affected services are shown, namely harvesting, recreation, water supply, and biodiversity maintenance. Forest harvesting is disrupted due to damaged timber wood, damaged trees, destroyed infrastructure, and devastated habitats. In the long term, foresters also face losses because of the expansion of disease-causing fungi and insects affecting trees that are weakened or stressed. After the Elbe flood in 2002, forestry in Saxony experienced a financial loss of approximately 8.4 million euros (Sächsisches Landesamt für Umwelt und Geologie 2004). IP19 verbally confirmed that cultural services such as recreation and education were also definitely disturbed during and after the Elbe flood 2002. The Elbe floodplains are a popular recreation area. However, it was not possible to enter the floodplains for several months. Due to a tangible decrease of tourists in 2002 and 2003 several small inns and hostels went bankrupt and had to close their businesses. Figure 5.2 shows the development of the number of accommodation facilities for the three districts Meißen (Saxony), Dessau and Wittenberg (Saxony-Anhalt) between the years 2002 and 2004. These districts were heavily impacted by flooding in 2002, which was reflected in a visible decrease of accommodation facilities in 2003.

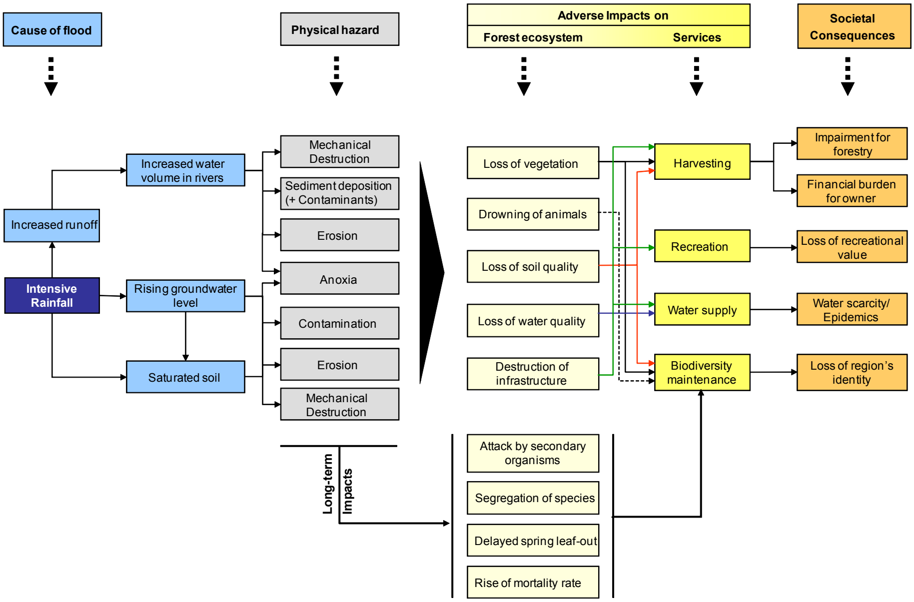
Figure 5.2: Decline of accommodations after the Elbe flood 2002



Source: Federal and Provincial Statistical Offices 2006

When river water infiltrates into the groundwater layers during a flood event, many wells in the affected area cannot deliver drinking water any more and have to be removed from the network. The reason is the high quantity of pollutants in the water, which reduces water quality (Wricke et al. 2003). IP20 and IP21 confirmed that during several flood events in the past, water treatment facilities had to be closed temporarily. However, redundant water facilities could always be added to the network, preventing the people from suffering water shortages. It is extremely important to safeguard the ecosystem service 'water supply' against flood impacts as this service fulfils basic human needs. Biodiversity maintenance is another ecosystem service impacted by flooding of forest ecosystems. In particular, extreme flooding causes significant damage and mortality among a forest's fauna and flora. However, the separation of species can also be considered as a positive impact on the successive establishment of flood-adapted species. Thus, the service biodiversity maintenance has to be treated with caution when speaking of a negative impact.

Figure 5.3: Impact chain for forest sector and river flooding



Source: Author

The previous paragraphs have shown that the societal consequences of extreme flooding are significant. When ecosystem services fail or are disrupted, economic, cultural, and social consequences have to be expected at various spatial/ geographical levels. A special feature of the SES 'forest' is that flood consequences do not only appear within the inundated areas or their closest vicinity, but show effects at different spatial scales and levels. Forests in Germany are either privately owned or are public (run by a federation, federal state, or municipality). Hence, reconstruction measures have to be carried out and financed by the respective owners. Another example for severe impacts on the social system is the failure of the service water supply. As the affected wells and water treatment facilities are part of a large cross-boundary network the consequences of a failure can, in the worst case, affect numerous districts, as IP20 confirmed in the interview. Thus, individuals, communities, or even the federation, have to deal with the consequences of the flood event A summary of the described elements and processes is provided in figure 5.3.

Agricultural sector:

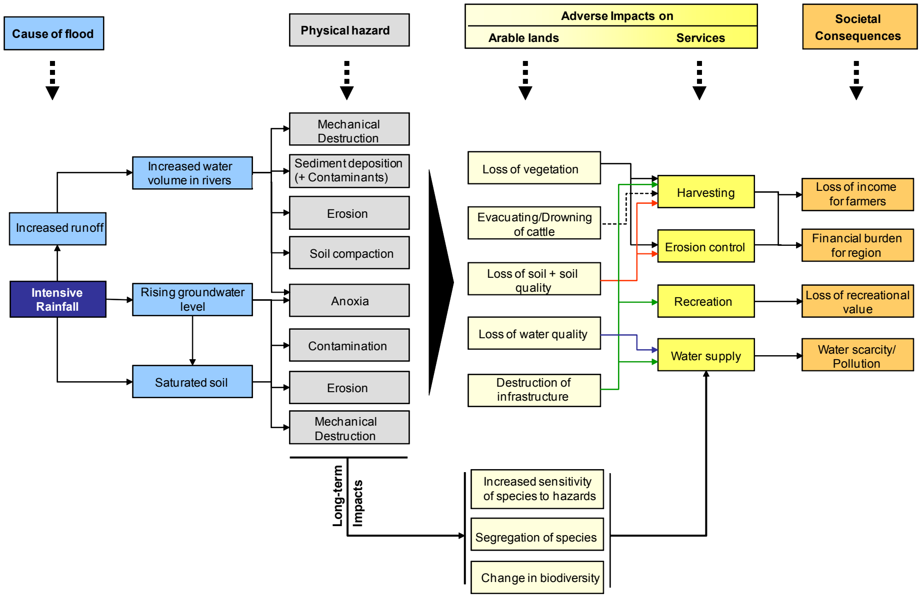
A variety of physical hazards impact arable lands during a flood event. Mechanical destruction of infrastructure and crops, the deposition of sediments (often toxic), erosion of valuable land, the compaction of soil, and suffocation of plants and animals all affect arable lands.

Pivot et al. (2000) mentioned two types of damage caused by flooding: damage affecting the field's permanent characteristics, and damage to the crop grown there at the time of flooding. Flooding has a major impact on the field characteristics because of the presence of water and, probably to a greater extent, because of what is added or taken away by the water flow. Usually, floods transport solid materials as well as large amounts of dissolved substances. The materials can have a fertilizing and positive effect. However, often those sediments have negative consequences as deposits are often sands or contaminants which reduce the productive potential of a field's soil. Rising water levels mobilize toxic materials and transport them downstream. Inorganic pollutants such as heavy metals often come from present or abandoned mining sites. High concentrations of heavy metals in soil and groundwater exist, for instance, in the region of Bitterfeld along the Mulde River in Saxony. The chemical industry, sewage treatment plants, as well as pesticides and fertilizers are often sources of organic materials washed out by the river water. Many industrial and mining sites have been closed in recent decades. However, old dump sites are still diffuse sources for pollutants (Geller et al. 2004). The flood also transports different elements that are undesirable in agricultural fields: dead wood, detritus, etc. Some damage cannot be repaired (modification of soil structure) while other damage requires considerable cleaning efforts. Flooding can also erode parts of the field, carrying the eroded material downstream. Soil is washed away, holes can form, banks subside, and fences and installations are torn down. Moreover, water causes the ground to compact in proportion to the height of the flood. This effect constitutes a genuine reduction of agronomic potential when floodwater height exceeds 40 cm. In the case of long-term submersion, the impact of soil destructuration is exacerbated by a negative effect on the soil's biological activity, in particular via the elimination of earthworms (Pivot et al. 2000). The damage caused to crops in the field when flooding occurs is also considerable. This is due to the anoxia suffered by crops, the weight of the water and the current, which flattens and tears away vegetation. The addition of solid materials (e.g. mud, sand) and toxic substances can also have negative effects by reducing photosynthesis due to deposits on leaves, reducing the quality of fodder, and by phytotoxicity. Floods also have secondary effects: holding up work, leaching fertilizing elements spread before submersion, denitrification, and contribution of seeds of adventitious plants and actions favourable to the later development of fungi on crops (IP11, IP12). Thus, it is important to consider that damage to a farm often differs from that observed for the flooded fields.

Flood-induced physical hazards have many consequences in the agricultural sector. The loss of crops or seedlings directly affects the provisioning ecosystem service of 'harvesting'. IP11 and IP12 confirmed that the Elbe flood caused widespread crop damage. Moreover, the farmers complained about the loss of soil fertility and soil quality being a long-term consequence of flooding triggered by soil erosion or sedimentation. The losses of crops result in a reduction of the erosion control function in agricultural areas. When bare soil is exposed to water and wind, erosion can occur much more easily than when that soil is covered by vegetation (IP7). Apart from crops, livestock is also affected during flood events. Both cattle kept free on pastures and cattle kept under cover are affected. Cowsheds are usually located behind the dykes, but especially during extreme events they are also prone to being flooded. IP11 und 12 reported that in 2002 one of the main problems was to organize the evacuation of cattle. As farmers were not prepared they had to react spontaneously to the flooding. They had to find safe locations to accommodate and supply the cattle. IP11 asserted that particularly in the case of unexpected or fast flooding (e.g. dyke breaching) cattle can drown. Another serious aspect is the risk of infections or even epidemics. Unclean water or pollutants that get into the food through the food chain are often the causes of this (Geller et al. 2004). Hence, as in the forest sector, it is crucial to control the water quality of each well in an agricultural area as an increase of inorganic and organic substances must be expected during extreme flood events. Some examples of epidemics in Norway and Germany following flooding are mentioned in Geller (2004). The destruction of infrastructure in inundated areas must also be considered. Fences, barns, roads, and trails have to be rebuilt and re-established after every flood event. Farmers are hampered in their work but so are emergency teams. In recreational areas such as the 'Biosphärenreservat Mittelelbe' it is also the case that the public cannot benefit from the recreational and cultural services until the original conditions are restored. The tourism sector of a region can thus be heavily affected.

Hence, the ecological and social subsystems are seriously affected by extreme flood events. The societal consequences are manifold and show effects throughout various geographical social and administrative levels. For example, when a large area is affected and large amounts of crops are destroyed, this has consequences for farmers, employees working in the agricultural sector, and for the population when the production and delivery chain is disrupted, leading to a rise in prices (IP18). A summary of the described elements and processes is provided in figure 5.4.

Figure 5.4: Impact chain for agricultural sector and river flooding



Source: Author

5.3.2 Analysis of the 'susceptibility' component

An analysis is conducted considering the susceptibility component of vulnerability which provides information about the condition of the social and ecological subsystem of the forest sector.

Forest sector:

Experts from the forestry sector (IP1-IP5) confirmed that beside flood intensity it is the health of a forest ecosystem that determines the extent of damage in a forest ecosystem during and after a flood event. Potential perturbations or stressors in a forest ecosystem can be triggered by former hazardous events such as floods, storms, or forest fires. Also, insect diseases or fungi can impair the ecological balance in forests. Furthermore, soil conditions are often mentioned in the literature. Kennel (2006) asserts that the discharge behaviour in forest ecosystems is dependent on forest type and soil characteristics. Soil texture, porosity, soil compaction etc. are some of the properties that determine the infiltration rate or water storage capacity of a soil, and thus can mitigate flood impacts (LFW 200; LFW 2004; Schüler 2006). Drainage is generally reduced by compaction from heavy forest machinery. This is why the location and density of logging trails requires careful consideration by forest planners.

Apart from forest and soil characteristics, the period of occurrence as well as climatic and hydrological conditions strongly influence the susceptibility of a forest ecosystem. Hence, flooding during the growing season is more harmful to trees than flooding during dormant periods (Iles and Gleason 1994). Furthermore, it makes a difference whether soil is saturated and the groundwater table is high due to long-term rainfall before the actual flood event.

The susceptibility of the social subsystem is less tangible in comparison to the ecological subsystem. According to the vulnerability framework it is important, however, to work out which perturbations and stressors have influences on the condition of the social subsystem. The conclusion drawn from the interviews and literature is that socio-economic conditions do indeed have an influence. At the level of analysis applied in this research, it is especially important to take economic aspects into account. Further aspects such as, for example, political instability or corruption were also identified as potential stressors. These are not meaningful for Germany though, since Germany is a stable democracy. In addition, the degree of dependency of the social system on certain ecosystem services was mentioned as a factor that increases susceptibility in the forest sector (IP17, IP18).

Agricultural sector:

Beside hazard characteristics such as flow velocity, height of water in the field, duration of submersion, and the quantity and nature of the solid materials transported by the flood, there are numerous internal system characteristics that influence the susceptibility of the agricultural sector at a particular place. According to Pivot (2000) susceptibility results from field characteristics such as micro relief, presence of fences and miscellaneous equipment, as well as soil and crop properties.

For instance, soil erosion potential is determined by different factors: soil texture, topography, and vegetation cover. Vegetation is the best protection against soil erosion. Grasslands and year-round field fodder cover are recommended in Strotdrees (2005) and Frielinghaus and Winnige (2000). Also, the choice of tillage system influences the erosion potential. Crop rotation or strip cropping are identified as effective measures to protect soil from erosion. Thus, in certain areas the erosion of soil by water is more likely than in others. Another important aspect is the contamination potential in flood-prone areas. As shown in chapter 5.3.1, the mobilization of pollutants and solid material is a serious problem during flooding. IP6 - IP13 agreed that in industrial regions as well as in the vicinity of sewage treatment plants there is a high risk of contamination. IP10 suggested the use of brownfield maps to determine contamination potential. Van der Ploeg (2006) asserts that soil compaction in agriculture increases with the use of huge, heavy machines. Modern machines can weigh between 30 and 50 tons. Soil compaction enhances the susceptibility of agricultural fields, as it reduces not only soil quality but also the infiltration rate. The reaction of soil to heavy machinery depends on the soil texture and the soil organic matter (SOM). Moreover, it makes a difference whether soil is wet or dry when it is cultivated (van der Ploeg 2006).

Susceptibility in the social subsystem is, similar to the forest sector, mainly influenced by the economic situation of farmers, the region, or the country. IP6 and IP11 reported that farmers with low income or debts were hit particularly hard by the flood event in 2002 and were thus strongly dependent on financial compensation and subsidies. Furthermore, the susceptibility is naturally very high amongst farmers if the last disastrous event occurred just recently. Without enough recovery time it becomes difficult for farmers to cope with the consequences of flooding again. However, it is not only the economic situation of the farmers which accounts for the susceptibility of the agricultural sector but that of the whole region, since many different actors across multiple scales and levels are involved in the sector (IPCC 2007).

5.3.3 Analysis of the 'capacities' component

Capacity, as the third component of vulnerability, is structured again in three subcomponents according to the vulnerability framework used in this research. The interviews and literature were analysed with regard to the elements and processes that contribute to a flood-resilient SES.

Forest sector:

The capacities of a forest ecosystem are mainly dependent on the flood-tolerance and adaptive behaviour of forest species (Bratkovich et al. 1993; LFW 2004; Swanson et al. 1998). The natural vegetation in floodplains ranges from shrubs to softwood and hardwood tree species. Before mankind altered the original state of forests and rivers, forest ecosystems successively developed with regard to the respective flood conditions in a region. Today, the situation is different, as already explained in previous chapters. Hence, it is necessary to explore the robustness of forest ecosystems at a certain place. According to Bratkovich et al. (1993), a variety of factors contribute to the flood-tolerance of a forest. However, it is especially forest characteristics such as forest age, vigour, and forest type that determine a forest's capacity to resist and adapt. Experts IP2, IP3, and IP14 also stressed the importance of forest vitality and the existence of potential floodplain vegetation. Examples of flood-tolerant tree species can be found in Iles and Gleason (1994), Bratkovich (1993), Dister (1983), Glenz et al. (2006), Lehmann (2000) and Schutzgemeinschaft Deutscher Wald (2001). Floodplain forests in Germany are usually dominated by softwood species such as Salix Alba (silver willow) and Populus Nigra (black poplar). Typical hardwood tree species in German floodplains are Quercus Robur (common oak), Ulmus Laevis (white elm), Ulmus Minor (field elm) and different types of Fraxinus (ash tree). Additionally, the experts mentioned forest size and degree of fragmentation as important aspects determining the degree of forest capacities. Large and non-fragmented forests provide better shelter for wild animals in the case of flooding. Swanson et al. (1998) assert that the reaction of forest ecosystems to extreme river flooding is mainly dependent on the way a forest is managed. For example, roads may be sources of debris flows or can even trap debris flows before they encounter larger channels. The use of heavy machines causes soil compaction and reduces the infiltration rate. Clear-cutting in forests enforces damage as it removes protection against soil erosion.

In addition, Swanson et al. (1998) recognize the importance of habitat complexity in the response of biota to flooding. This implies that natural types and levels of habitat should be maintained so that flooding can provide ecological benefits. Schüler (2006) concludes in a paper that sustainable management is one of most important measures for establishing a healthy and protective forest ecosystem. This opinion is supported by IP2, IP4, and IP5.

Coping and adaptive capacities in the social subsystem can also be derived from the interviews conducted. Coping refers to the reactions and measures during the flood event, as well as reconstruction afterwards. Adaptive capacities are defined as long-term methods including learning processes (see Table 5.2). IP1, IP2, IP5, and IP 18 considered the availability of sufficient financial resources as the most effective and important coping strategy in the forest sector. Monetary resources are needed for the clearance of damaged sites, reconstruction of infrastructure, and reforestation. In the case of large-scale damage and high financial losses, support is usually provided by the district, federal state, or country. IP2 reported that the municipality 'Leimersheim' received substantial financial compensation from the district and even the EU. The existence of a functioning disaster management was also emphasized by IP3 and IP4. As a disaster management system helps to secure dykes and organize evacuation or other measures it has an important function. IP1-IP5 agree with each other that flood-adapted species should be favoured in a flood-prone forest in order to improve ecosystem robustness. Furthermore, sustainable forest management meets the demands of careful and conservative use of forests, for example, heavy machines are avoided, as is clear-cutting. IP2 emphasizes the importance of the establishment of protection areas which aid the implementation of sustainable management. A further crucial aspect was named by IP1, IP2, and IP4: risk awareness. The experts perceived that learning and adaptation processes were intensified after an extreme event. Examples are the provision of funding for respective projects or the enhancement of protection measures and disaster management. The establishment of redundant structures is also an important step towards the adaptation to flooding. IP18, IP20, and IP21 mentioned networks created for a safe and continuous supply of drinking water. If one water plant fails, as happened, for example, in Dresden in 2002, water can be delivered from other sources in the region. Hence, the reservoirs in the 'Osterzgebirge' (a mountainous region in Saxony) enabled the maintenance of the water supply for Dresden in 2002. In Figure 5.5 the impact chain for forest is completed by incorporating basic feedbacks and processes in the graphic. The societal consequences of flooding of forest ecosystems depend in the first instance on the degree of ecosystem robustness. The more robust the forest ecosystems, the less the ecosystem services are constrained. The social subsystem deals with damage and service failures with all coping capacities available. In the long term, adaptive strategies are undertaken in order to improve flood prevention and preparedness. These measures influence the causes of the flood (e.g. change of the river bed or construction of retention areas) or the ecosystem itself (e.g. change of land use).

Agricultural Sector:

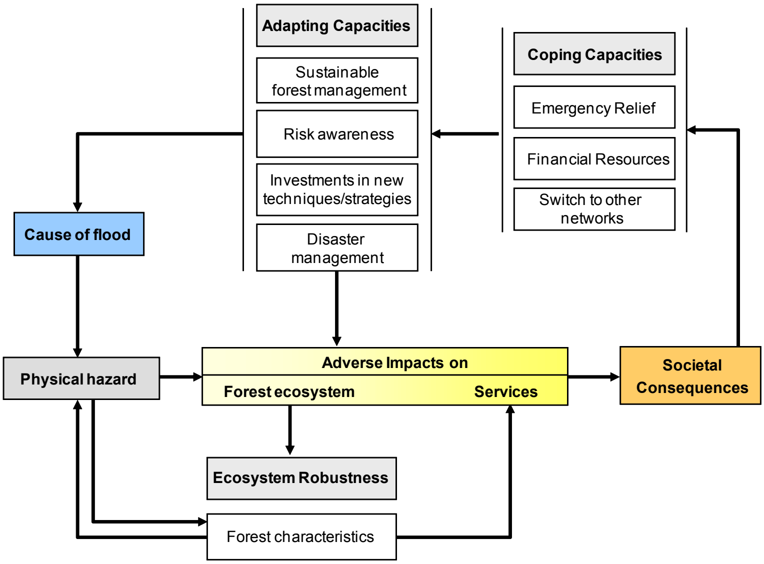
A major factor influencing ecosystem robustness of arable lands is the type and variety of species cultivated in inundation-prone areas. The species' response and resistance to anoxia, waterlogging, and diseases is of great importance (Pivot et al. 2002). Additionally, soil properties play a considerable role regarding the capacities to resist flooding. Infiltration rate, soil texture, porosity and water storage capacity are soil properties that determine the degree of surface run-off as well as the soil's capacity to resist erosion and compaction (Frielinghaus and Winnige 2000; Strotdrees 2005). Thus, vegetation and soil characteristics have to be taken into account when measuring ecosystem robustness.

The coping measures or strategies that farmers and organizations apply in the case of flooding include recovering the crop, adjusting the technical sequence of the method of cultivation, and replanting the crop (Pivot et al. 2002). Furthermore, fences and other damaged installations have to be rebuilt or repaired. All these measures require a certain financial capacity of the farmers. Financial deficits were evened out during the last extreme events by the federation, federal states, counties, or even the EU (IP6, IP10, IP11). IP6 confirmed that "generous" compensation was paid after the Elbe flood of 2002. Farmers can also take out insurance. However, this strategy is not very common amongst farmers yet as insurance policies in designated flood-prone areas are usually very high (IP11). All experts saw the availability of financial resources as the most important coping capacity during and after flood events. In addition, the existence of a functioning disaster/emergency management system as well as the informal cooperation between farmers and inhabitants of villages and communities were regarded as being of great importance by the experts. IP17 reported that there were large differences across regions regarding disaster management. The municipality 'Meißen' has an emergency management team working on a volunteer basis. That means that there is no professional disaster management team that organizes the relief in the case of flooding. Hence, the people are not professionally trained and are not part of the official dissemination of flood relevant information across districts or federal states. Moreover, the provision of sandbags and their subsequent disposal is not free. By contrast, in the municipality 'Pirna' a professional disaster management team exists that coordinates all measures and provides equipment, for example, sandbags. In 'Pirna' the disaster management team has access to actual flood information and can thus disseminate this information to the habitants (own observations during the Elbe flood 2006). The quality and quantity of disaster aid is significant for the affected farmers. In Germany, disaster management is organized at district level. At local level, volunteers contribute to dyke protection and emergency aid. The evacuation of cattle is an important task and coping measure. However, both IP11 and IP12 stated that during the Elbe flood in 2006 evacuation plans were inadequate. A further coping response to the disruption of important ecosystem services is the use of redundant structures or networks. An example of the supply of sufficient drinking water has already been given for the forest sector. Farmers or farmer cooperatives that owned additional cowsheds, pastures, and grasslands a safe distance from the inundations took advantage of the fact that they could evacuate cattle without the desperate search for an appropriate location.

Adaptation measures to flooding are manifold. One popular strategy of farmers is to adjust the type of land use in flood-prone areas. Hence, throughout Germany, inundation areas (land between the river and the dyke) are mostly dominated by pastures and grasslands. However, for economic reasons land use is often intensive, in order to make the yield more profitable (IP12). Behind the dykes farmers usually feel safe enough to cultivate all possible crop types, such as wheat, maize, and sugar-beet. Some farmers have already adopted the mulch-seeding procedure to protect their soil from erosion and soil compaction. Still, conservative management remains rare (IP12). Numerous scholars have proved that conservative tillage systems have a substantial influence on the infiltration rate of soils. Conservative tillage uses a high coverage of mulch and a minimum of tillage in comparison to the deep ploughing and heavy machines of conventional management systems. Mulch prevents the soil from siltation/sealing and promotes high biological activity (Schmidt et al. 2006; Schönleber 2006; Wilcke et al. 2002).

The federal states and the federation are classifying more and more land as protected areas. The advantage of this strategy is that only extensive land use is permitted, meaning that only conservation tillage and little or zero pesticides and fertilizers may be used. However, the implementation and monitoring of the land use depends on the status of the protected area. A side effect of declaring protected areas is the need for maintenance of biodiversity and rare species (IP12).

Figure 5.5: Complete impact chain including responses and feedbacks within the forest sector

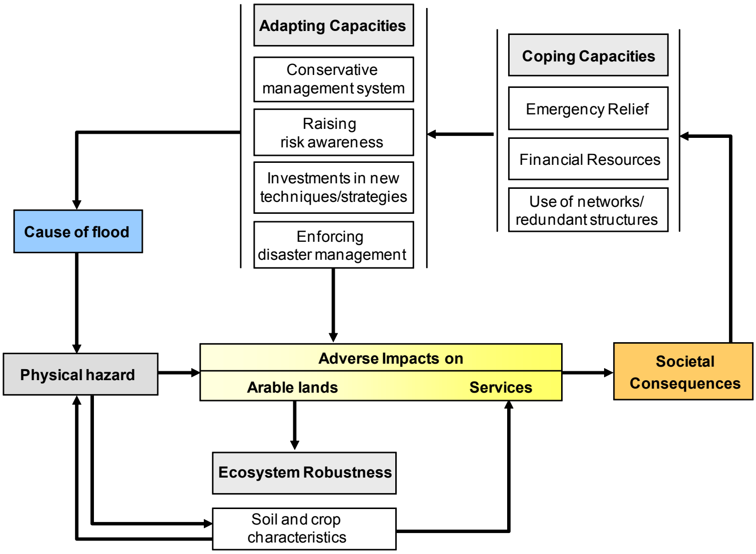


Source: Author

Finally, the implementation or establishment of adapting strategies depends basically on the occurrence of the last extreme event, as all experts confirmed (see forest sector).

Figure 5.6 illustrates the feedbacks and processes within the agricultural sector. The failure of ecosystem services depends mainly on the capacities of the agricultural ecosystem. Subsequently, the social subsystem copes with damage and disruption of services. In the long term, adaptive strategies are undertaken in order to improve flood prevention and preparedness. As already described above, adaptive capacities have a certain influence on the causes of floods as well as on the ecosystem itself.

Figure 5.6: Complete impact chain including responses and feedbacks within the agricultural sector



Source: Author

5.3.4 Review of frequently used environmental indicator approaches

Some studies cover similar elements and target similar issues as this research. These studies have been analysed to determine prominent indicators for both sectors. The analysis concentrates on main objectives, general concept, users addressed, and indicators used.

The first study deals with the development of forest sector indicators and was conducted by the World Bank for Central America (Linndal 2000). The main objective is the design of indicators to monitor sustainable development at regional and national level for different sectors. The forest sector example demonstrates how policy relevant issues can be addressed through the use of available information and existing data sources. The indicators are to capture basic data, trend data, impact data, as well as economic and social impact data. End-users are policymakers at national level. Numerous indicators are used to describe sustainable development. Only a selection of indicators is mentioned here.

Indicators: Forested area, % rate of change in forest area, volume of trade, forest ownership, number of people depending on forest resources, index of biodiversity richness, number of forests, number of recreational visitors, etc.

The Heinz Centre (The Heinz Centre for Science Economics and the Environment 2002) published a series of ecosystem indicators for different sectors with the objective of reporting on the extent, condition, and use of the lands, waters, and living resources of the United States. The indicators were selected through collaboration among government, environmental organizations, the private sector, and the academic community. The report identified ten major characteristics of ecosystem condition and use that together provide a broad, balanced description of any ecosystem type. After selecting indicators, the availability of data sources had to be reviewed. High quality data with an adequate geographic coverage and a reasonable likelihood of future availability were used. The report addresses decision makers at any administrative level and the public. A variety of indicators for forest and farmland are listed below:

Indicators – Forest: Forest area, forest ownership, forest type, forest management, forest fragmentation, carbon storage, nitrate in forest streams, at-risk native species, forest age, forest disturbances, timber harvest production, recreation in forests.

Indicators – Farmland: Total cropland, fragmentation, nitrate in groundwater, pesticides in farmland, soil organic matter, soil erosion potential, soil biological condition, status of animal wildlife, major crop yields, agricultural output, monetary value of agricultural production.

The Organisation for Economic Co-operation and Development (OECD) has also developed a list of indicators concerning the environmental performance of agriculture. Using standard indicators, definitions, and methods of calculation, OECD (2001) provides results and trends of environmental conditions in agriculture at national level. Four different categories have been developed to capture agricultural performance. Thus, socio-economic aspects, farm management, use of farms and natural resources, and environmental impacts are considered in the study. The agri-environmental indicators are primarily aimed at policymakers and the wider public interested in the development, trends, and the use of indicators for policy purposes.

Indicators: agricultural output, farm employment, number of farms, agricultural land use, farm income, organic farming, pest management, soil cover, land management practices, nitrogen balance, pesticide use, water stress, risk of soil erosion by water and wind, water quality indicator, water retention capacity, species diversity, structure of landscape.

The German federal state of Bavaria has also invested in the development of an indicator system in order to monitor environmental conditions, changes, and trends. The indicators are grouped into different categories that are derived from the PAR model (Blaikie et al. 1994). Hence, the indicators describe driving forces, pressures, current state, and impacts of the environment. The study aims at harmonizing data throughout the country in order to retrieve one consistent indicator set for Germany using available data sources (Bayerisches Landesamt für Umweltschutz 2004).

Indicators: Protected areas, conservative agricultural management, at-risk species, pesticide and fertilizer use, water quality, brownfields, environmental management, land consumption.

All mentioned studies deal with the development of environmental indicators. Although they have different objectives, they use similar categories and can therefore be compared with this research. The categories are, for instance, the state of the environment, the susceptibility of the ecosystems, the intensity of human use, etc. Additional studies have been reviewed and analysed for this research. However, not all of them have been presented here.

5.4 Identification of an indicator set

In this chapter the development of an indicator set for forest and agriculture is described. The structure of the section follows the methodological approach illustrated in figure 5.1.

5.4.1 Development of vulnerability categories

The identification of vulnerability categories is considered as a pre-step for the indicator development in this research. Categories have a descriptive purpose and are of a generic nature. Moreover, they help to structure the superordinate concept of vulnerability. Hence, categories are developed for every vulnerability component. In this study the categories are identified by analysing the impacts of flooding as well as by analysing susceptibility and capacities in the forest and agricultural sectors with regard to river floods (see Chapter 5.3). The analysis made obvious that the relevant categories are almost identical for both sectors. A list of categories is provided in table 5.2.

The developed categories provide, on the one hand, orientation for the indicator development, and on the other hand, act as targets or models to reduce vulnerability. For example, vulnerability can be reduced when sufficient coping capacities are available. This can be achieved by (1) sufficient financial resources, (2) effective emergency relief, and finally, (3) sufficient redundant networks.

The category ‘political instability’ has been regarded as very important for a vulnerability assessment by experts and in other approaches. However, this category is not used in this research as currently Germany does not face major political constraints or instabilities that might influence flood disaster management.

Table 5.2: Important categories to be considered for vulnerability assessment

Vulnerability component	Vulnerability sub-component	Categories, Description
Exposure		*Ecological system exposed*: forest ecosystems/arable lands exist in the unit of analysis and can be potentially flooded.
		Social system exposed: employees, owners, or organizations involved in the respective sector.
Susceptibility	Social conditions	*Political instability:* a political situation that hinders the implementation of measures or the provision of emergency relief and support can make the social system very susceptible to extreme flood events.
		Economic drawbacks: regions that are economically disadvantaged do usually not dispose of high financial savings or resources.
	Ecosystem conditions	*Pre-damages:* if an ecosystem still has to recover from previous hazardous events or serious disruptions, it is more susceptible to upcoming hazards.
		Contamination potential: heavily loaded groundwater, soils or atmosphere do already exert a certain stress on forest ecosystems. In the case of flooding the situation becomes even tenser as the load rises or gets mobilized.
Capacities	Ecosystem robustness	*Forest/Arable land characteristics:* the characteristics of vegetation, soils, and water provide valuable information on the ecosystem's robustness.
	Coping Capacities	*Financial resources:* are needed to install protection measures, compensate yield losses and to reconstruct damaged infrastructure.
		Emergency relief: the existence of an organized and functioning emergency relief facilitates coping during a flood event.
		Redundant networks: the existence of redundant structures and networks helps to avoid the complete failure of ecosystem services.
	Adapting capacities	*Management type:* the way a forest is managed influences the susceptibility and ecosystem resilience of a sector.
		Risk awareness: stimulates the consequent enhancing and enforcing of adaptation strategies. The longer the time span between the last extreme event and today, the more decreases the awareness.
		Investments: the more funding and investments are provided for research and new technologies, the more can be learned about how to adapt and cope with extreme events.
		Disaster management: information dissemination, improving the efficiency of internal structures, training of people as well as the adjustment of technical protection measures belong to the tasks of a functioning disaster management.

Source: Author

5.4.2 Preliminary indicator list

The preliminary indicator list has been developed from the findings of expert interviews, impact analysis, and the literature review. In table 5.3, the indicators are directly grouped within their respective components and categories.

Table 5.3.1: List of potential indicators for the forest sector

FOREST SECTOR			
Component	Sub-component	Category	Indicators
Exposure		Social system exposed	• People employed in the sector • Timber production • Gross value added
		Ecol. system exposed	• % Forested area
Susceptibility	Human Condition	Economic drawbacks	• Unemployment rate federal state • Unemployment rate district • Financial debts of municipality • Insolvency rate
	Ecol. Condition	Pre-damages	• Windfall areas • Crown defoliation • at-risk species • damages from insect diseases or forest fires
		Contamination potential	• Groundwater quality • Nitrate in forest streams • Pesticide use
Capacities	Ecosystem robustness	Ecosystem characteristics	• Species richness • Fragmentation • Forest age • Forest size • Forest type • Potential natural vegetation
	Coping Capacities	Emergency relief	• Early warning system • Trained/organized teams • Availability of equipment • Cooperation between actors • Existence of plans and maps
		Financial resources	• GDP per capita of federal state • GDP per capita of district • Personal income • Side income
		Redundant networks	• Existence of water supply network
	Adaptive Capacities	Land Management	• Sustainable forest management • Reforestation rate • Protected areas
		Investments/ Disaster Management	• Money invested in new research or flood protection
		Risk awareness	• Occurrence of last extreme event

Source: Author

Table 5.3.2: List of potential indicators for the agricultural sector

AGRICULTURAL SECTOR			
Component	Sub-component	Category	Indicators
Exposure		Social system exposed	• People employed in the sector • Gross value added • Agricultural output
		Ecol. system exposed	• Farmland
Susceptibility	Human Condition	Economic drawbacks	• Unemployment rate federal state • Unemployment rate district • Financial debts of a municipality • Insolvency rate
	Ecol. Condition	Pre-damages	• At-risk species • Soil erosion potential
		Contamination potential	• Contaminated sites • Potential contaminating sites • Pesticide/Fertilizer use • Groundwater quality • Water quality of streams
Capacities	Ecosystem robustness	Ecosystem characteristics	• Filter and buffer capacity • Water retaining capacity • Crop type
	Coping Capacities	Emergency relief	• Early warning system • Trained/organized teams • Availability of equipment • Cooperation between actors • Existence of plans and maps
		Financial resources	• GDP per capita of federal state • GDP per capita of district • Personal income • Side income
		Redundant networks	• Existence of water supply network
	Adaptive Capacities	Land Management	• Organic farming • Protected area
		Investments/ Disaster Management	• Money invested in new research or flood protection
		Risk awareness	• Occurrence of last extreme flood event

Source: Author

5.4.3 Evaluation of indicators

The preliminary indicator set is evaluated by means of a number of selection criteria. An indicator is only accepted for the final indicator list when it fulfils the selection criteria to a certain extent. The following criteria have to be met:

Validity: An indicator has to reflect, as well as possible, a certain category or issue. Experts and literature determine the analytical validity of the indicator and facilitate evaluation. Full validity is difficult to guarantee as most categories cannot be measured that easily. It has to be accepted that the degree of validity depends also on the subjective opinion of the researcher.

Understandability: This is an important selection criterion in terms of practical use of the indicators for decision-making processes. However, if an indicator is absolutely necessary for the overall context, it can be included despite poor understandability.

Data availability and quality: Data has to have adequate geographic coverage to represent vulnerability across all districts in Germany. However, availability is not enough. Data has to be easily accessible by interested parties. Although data is produced by public institutions, access to researchers is sometimes extremely constrained by high costs. Moreover, a crucial aspect is that sufficient data quality has to be met. This includes also the comparability of data across regions in Germany. As many data sets are collected by the federal states, different procedures are often applied. This has to be kept in mind when using country-wide data sets.

Reproducibility: An approach is developed with this research that can be operationalized and repeated after a few years. Only by using reproducible methods and data can an approach be used in future.

The evaluation of indicators is carried out on the basis of expert judgment by using the ranks and symbols shown in table 5.4. Potential cross-correlations will be tested in chapter 7.

Table 5.4: Selection criteria and rankings for potential indicators

	Very high	High	Middle	Low	Very low
Selection Criteria	xx	x	xo	o	oo

Source: Author

Very high stands for an excellent performance of the respective selection criterion; *very low* indicates that very low performance is reached. Table 5.5 lists all potential indicators and evaluates their quality with regard to their validity, understandability, data availability, data quality, and reproducibility.

Table 5.5: Evaluation of all potential indicators with regard to four selection criteria

Indicators Forest	Validity	Understandability	Data availability/data quality	Reproducibility
People employed in F.S.	xx	xx	xx	xx
Timber production	x	xx	o	o
Gross value added	xx	xx	xx	xx
Forested area	xx	xx	xx	xx
Unemployment rate F.S.	xx	xo	xx	xx
Unemployment rate district	xx	xo	xx	xx
Financial debts of municip.	x	x	o	o
Insolvency rate	x	xx	o	o
Windfall areas	xx	xx	xo	xo
Mean crown defoliation	xx	xx	xx	xx
At-risk species	x	xo	xo	o
Insect diseases/ forest fires	xx	xx	oo	oo
Groundwater quality	x	x	o	o
Nitrate in forest streams	x	x	x	xo
Pesticide use	x	x	oo	oo
Species richness	xo	xo	oo	oo
Fragmentation	x	x		x
Forest age	x	xx	x	o
Forest size	xx	xx	o	xo
Forest type	xx	xx	x	x
Potential vegetation	xx	xx	x	o
Early warning system	xx	xx	o	oo
Existence of plans/maps	xx	xx	oo oo	oo
Trained/organized teams	xx	xx	oo oo	oo
Availability of equipment	xx	xx	oo	oo
Co-operational behaviour	x	x	xx	oo
GDP per capita of F.S.	x	x		xx
GDP per capita of district	x	x	xx	xx
Personal income	x	x	xx	xx
Side income	xx	xx	oo	oo
Water supply network	x	xo	oo	oo
Forest management	xx	xx	oo	oo
Reforestation rate	x	x	xx	xx
Protected areas	x	x	xx	x
Financial investments	x	xo	oo	oo
Occurrence of last extreme event	xx	xx	x	xo

Indicators Agriculture	Validity	Understandability	Data availability/data quality	Reproducibility
People employed in A.S.	xx	xx	xx	xx
Gross value added	xx	xx	xx	xx
Agricultural output	x	xx	o	o
Farmland	xx	xx	xx	xx
Unemployment rate F.S.	xo	xo	xx	xx
Unemployment rate district	xx	xo	xx	xx
Financial debts of municipality	x	x	o	o
Insolvency rate	x	xx	o	o
At-risk species	x	xo	xo	o
Soil erosion potential	xx	xx	x	x
Contaminated sites	xx	xx	o	xo
Potential contam. sites	x	x	x	xx
Groundwater quality	x	x	o	oo
Nitrate of streams	x	xo	x	xo
Filter and buffer capacity	xx	xx	x	xo
Water retaining capacity	xx	xx	x	xo
Crop type	xx	xx	o	o
Early warning system	xx	xx	oo	oo
Trained/organized teams	xx	xx	oo	oo
Availability of equipment	xx	xx	oo	oo
Co-operational behaviour	x	x	oo	oo
Existence of plans/maps	xx	xx	oo	oo
GDP per capita of F.S.	x	x	xx	xx
GDP per capita of district	x	x	xx	xx
Side income	x	x	xx	xx
Water supply network	x	xo	oo	oo
Organic farming	xx	x	xx	xx
Protected areas	x	x	xx	x
Financial investments	x	xo	oo	oo
Occurrence of last extreme flood event	xx	xx	x	xo

Source: Author

The selection of useful, reliable indicators starts with the criteria ‘data availability’ and ‘data quality’. This is due to the overall aim of this research which is to assess and map vulnerability on a regional scale. Thus, data availability is a major prerequisite and has to score at least high performance. Thereafter, the indicators are evaluated regarding the further criteria. 'Validity' and 'understandability' have to score at least high performance, whereas 'reproducibility' has to accomplish at least middle performance.

The criteria 'reproducibility' is in this case strongly correlated with 'data availability'. When data access is constrained or data is not available then it cannot be reproduced to create the outcomes of this research. Therefore, indicators with low or very low data availability automatically exhibit low or very low reproducibility. For example, the information on trained teams for emergency response is not available for the whole of Germany. Accordingly, data availability and reproducibility are very low.

5.4.4 Final indicator list

An indicator set for the forest and agricultural sectors was finally identified (see Table 5.6). The selected indicators are partially a compromise between what is desired and what is feasible. In some cases no data sets are available for the entire geographical scope, or data quality is not sufficient. The consequence is that categories such as 'emergency relief' and 'redundant networks' cannot be covered. Yet, it has to be mentioned that with enough manpower, time, and financial resources some additional data could indeed be collected.

Table 5.6: Final indicator list

FOREST SECTOR		
Component	Sub-component	Indicators
Exposure	Ecological system	• % of forested area
	Social system	• % of people employed in forest sector • % of gross value added forest sector
Susceptibility	Human condition	• Unemployment rate district
	Ecological condition	• % of damaged forest • Water quality index
Capacities	Ecosystem robustness	• Forest size • Forest fragmentation • Forest type
	Coping capacities	• GDP per capita of Federal State • GDP per capita of district • Mean income of private households
	Adaptive capacities	• Reforestation rate • % of protected areas

AGRICULTURAL SECTOR		
Component	Sub-component	Indicators
Exposure	Ecological system	• % of farmland
	Social system	• % of people employed in agricultural sector • % of gross value added agricultural sector
Susceptibility	Human condition	• Unemployment rate district
	Ecological condition	• Soil erosion potential • Water quality index • Potential contaminating sites
Capacities	Ecosystem robustness	• Water retaining capacity • Filter and buffer capacity • Dominating land use
	Coping capacities	• GDP per capita of Federal State • GDP per capita of district • % of farmers with side income
	Adaptive capacities	• % of organic farming • % of protected areas

Source: Author

One indicator that seemed to be of great importance for all experts could not be included in the indicator set. 'Occurrence of last extreme event' is a dynamic indicator which varies widely across districts in Germany. No complete data set has been available for this study that captures detailed discharge behaviour of all major German rivers. Thus, this indicator will only be applied as an example for the river-dependent risk scenario presented in chapter 8.

In some cases, data is not available or accessible but can be produced quite easily. For example, 'forest fragmentation' and 'forest size' could be calculated from existing land use data after developing a certain methodology. More details and information about the indicators, collection, and sources can be found in the next chapter

6. Indicator description and mapping

6.1 Overview of specification criteria

In this chapter several work steps are described that facilitate specification of the selected indicators and inform about technical, spatial, and analytical aspects. The following topics are addressed for the indicator description:

Units and scope: In a first step the measurement unit as well as the temporal and spatial scope of the respective data set are described. Different data sources and data types imply that data works at various different scales and levels. To inform about reproducibility of indicators and the actuality of data the temporal scope is mentioned as well.

Data source and data description: Data sources have to be named to guarantee a proper citation and to inform about the origin of data used for this approach. If alternative data sources exist, they are also mentioned. Moreover, a detailed description of the data set and time of collection is provided, which is needed to judge data quality.

Technical Note: A technical note is created to describe exactly how a variable is produced. For instance, the original data has been transformed to a relative variable, or a specific method was developed to create a proper proxy variable.

Relevance: It is necessary to elaborate on the relevance of each indicator for the approach in order to enhance understandability and to evaluate the indicators. This analysis shows the significance of each indicator for the whole approach.

Validity: In this step the technical and analytical validity of each indicator has to be analysed. Here the quality of the indicator is finally evaluated.

Visualization and Interpretation: Subsequently, the indicator is mapped. Spatial patterns are analysed and the distribution of data across German districts is briefly discussed.

6.2 Indicator mapping

The visualization of indicators is a crucial step in the assessment and mapping of vulnerability in this study. GIS[16] was used to conduct the various spatial and statistical operations that were necessary to visualize the issue that an indicator seeks to represent.

Moreover, in a number of cases the variable had to be derived from existing data first. These calculations have been carried out in GIS as well. The mapping of indicators is conducted with the aim of informing experts and decision makers about the existence and distribution of hot spot regions across Germany. Moreover, the indicator maps will facilitate the analysis and evaluation of the overall vulnerability index in chapter 8.

Mapping data in a GIS required the set-up of a database with spatial references. Some data was already available in a GIS data format; other data had to be converted or transformed to the proper format before using it in GIS. Therefore, an ID had to be assigned to each district and federal state. The official administrative codes have been used as IDs in this study. By means of the GIS function, INTERSECT polygon data could be assigned to the respective district ID. Table 6.1 provides an overview of the data sources, formats, and spatial scales.

---

[16] ArcGIS 9.1 was used in this research to calculate and map indicators and indices.

Table 6.1: Information about data used in this study

Data category	Source	Derived Indicator	Format/Type	Spatial scale
Soil data	European Soil Data Base (CEC 1985)	• Erodibility • Organic • CarbonContent (OCC) • Texture	Vector data Text files	Scale: 1:1,000,000
Forest data	Statistic Regional (Federal and Provincial Statistical Offices 2006)	• Area • Growth rate	Text files	District level
	CORINE Land Cover (UBA 2004)	• Size • Fragmentation • Type	Vector data	Scale: 1:100,000 cell size: 25 ha
Agricultural data	Statistic Regional (Federal and Provincial Statistical Offices 2006)	• Area • Organic farms	Text files	District level
Socio-economic data	Statistic Regional (Federal and Provincial Statistical Offices 2006)	• Grassland/pastures • Employees • GVA • GDP • Unemployment • Population	Text files	District level Federal state level
Environmental data	Water Quality Atlas (LAWA 2002)	• Water quality index	Vector data	no information
	Federal Agency for Nature Conservation (BFN 2007)	• Protected areas	Vector data	no information
	Offical Topographic and Kartographic Information System (ATKIS) (BKG 2006a)	• Contaminating sites	Vector data	1:250,000
Administrative data	Offical Topographic and Kartographic Information System (ATKIS) (BKG 2006b)	• Boundaries • Land area	Vector data	1:250,000

Source: Author

6.3 Indicator fact sheets and maps

In this chapter, detailed information about each indicator is provided by elaborating on the above-mentioned topics.

Sector: Forest	**Vulnerability component:** Exposure	**Sub-component:** Ecological-system
Indicator: % forested area	**Measurement unit:** %	**Spatial and temporal scope:** District level, update every four years
Data source: Statistic Regional, Federal Statistical Office 2006		**Further sources:** CORINE land cover 2000

Data description: ‘Statistic Regional’ is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. However, not all data is updated annually. The last collection of land use/land cover data took place in 2004.
Data type: Excel file

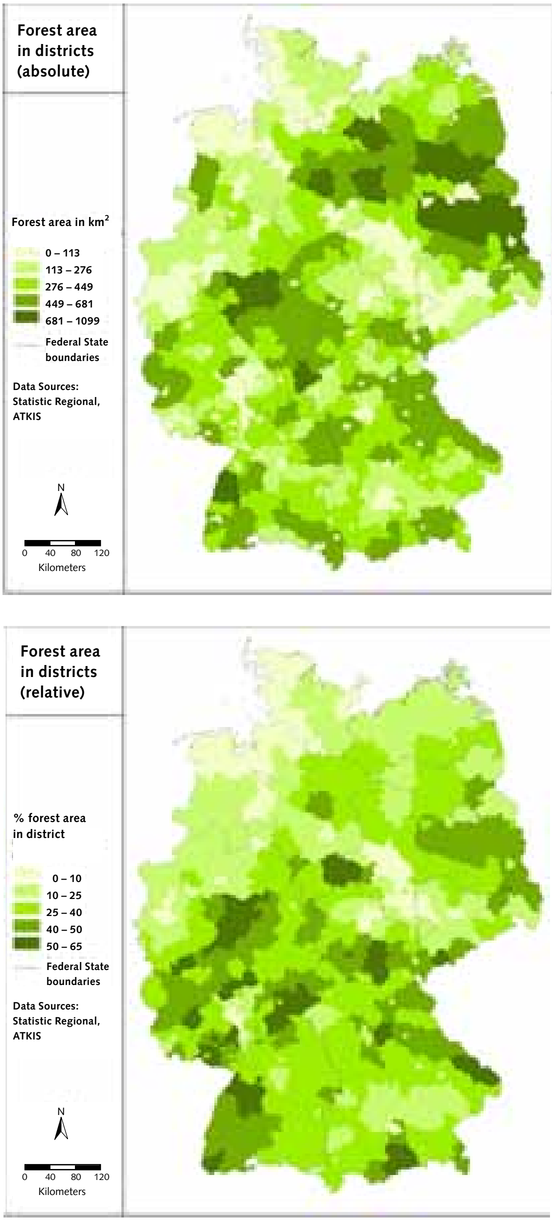
Technical note: The original data set on forested area [km²] in a district has been transformed to a relative variable. The percentage of land area covered by forests was calculated in order to compare the result across all German districts and district-independent cities. Thus, the forested area was divided by the total land area of a district.

Relevance: This indicator reveals how much forest land there is in each district. It is matter of fact that the more forested ecosystems exist, the more forest land can potentially become exposed to flooding. This means that functions and services might be interrupted or disturbed causing severe ecological and societal consequences.

Validity: The data set is technically valid. It is updated every four years and already shows slight changes in forested area per district. The data set is complete, without any missing values. One constraint is that the indicator reflects the total forested area in a district and not just forest ecosystems in potential inundation areas. This is due to the fact that no complete information on floodplains within all districts exists. If a scenario for a particular river is calculated, only forest stands in inundation areas should be considered.

Visualization/Interpretation: Although Germany is a densely populated country, two thirds of the land area is still covered with forest (see Figure 6.1). The absolute forested area is very high in north-east Germany and in the ‘Sauerland’ region in west Germany. The ‘Schwarzwald’ in south-west Germany is also densely forested. However, the percentage of forested area per district area shows a slightly different picture. The map reveals that especially the mountainous areas in Germany exhibit a high percentage of forests (50-65 %). For instance, the southern districts adjoining the Alps, the ‘Harz’ at the frontier between Saxony-Anhalt and Lower Saxony, or the Bavarian Forest in south-east Germany are densely forested. The least forested areas are found in north-west Germany where flat and fertile plains are mainly used for agricultural purposes, as well as in Saxony-Anhalt where the fertile soils (black earth) are intensively used for agriculture.

Figure 6.1: Absolute forested area in districts and percentage of forested area in district



Source: Author

Sector: Agriculture	**Vulnerability component:** Exposure	**Sub-component:** Ecological-system
Indicator: % farmland	**Measurement unit:** %	**Spatial and temporal scope:** District level, update every four years
Data source: Statistic Regional, Federal Statistical Office 2006		**Further sources:** CORINE land cover 2000

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. However, not all data is updated annually. The last collection of land use/land cover data took place in 2004.
Data type: Excel file

Technical note: The original data set on farmland [ha] in a district has been transformed to a relative variable. The proportion of land area covered by arable lands was calculated in order to compare the results across all German districts and district-independent cities. Thus, farmland area was divided by total land area of a district. Farmland includes pastures and grasslands (hayland).

Relevance: This indicator reports how much arable land there is in each district. It is a matter of fact that the more farmland exists, the more farmland can potentially become exposed to flooding in flat areas. This means that functions and services might be interrupted or disturbed, causing severe societal consequences. Knowing how much land is used for agricultural purposes is a crucial aspect of the assessment of exposure.

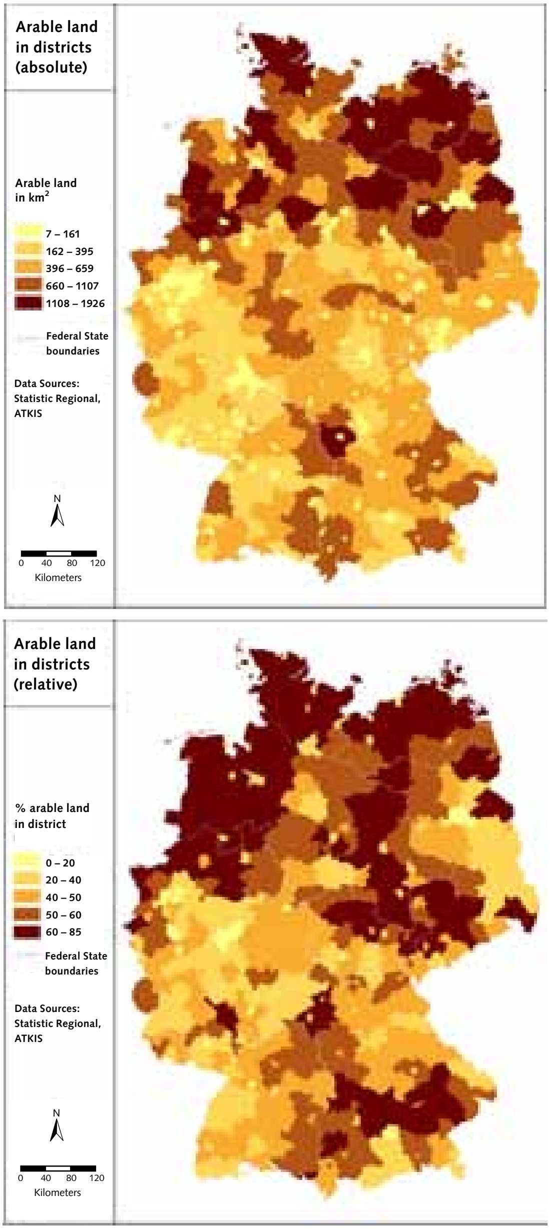
Validity: The data set is technically valid. It is updated every four years and already shows slight changes in forested area per district. The data set is complete, without any missing values. One constraint is that the indicator reflects the total forested area in a district and not just forest ecosystems in potential inundation areas. This is due to the fact that no complete information on floodplains within all districts exists. If a scenario for a particular river is calculated, only forest stands in inundation areas should be considered.

Visualization/Interpretation: Figure 6.2 shows that in Germany large areas are covered by farm land. In particular, north Germany and the eastern parts of Baden-Württemberg and Bavaria have large agricultural areas in the districts. Very little agriculture is conducted in the district-independent cities. The percentage of arable land across all districts highlights the high agricultural potential of north Germany. Additionally, in the 'Tertiary Hill Country'[17] in Bavaria and the glacially shaped landscape in Saxony and Saxony-Anhalt with its fertile soils (black earth) more than 60 % of the area of each district is farmland. Districts with a low percentage of farmland exist in west Germany and in central Germany. Poor soils and the changing relief of the low mountain ranges as well as the densely populated 'Ruhr Area' explain the low percentage.

---

[17] German: Tertiäres Hügelland.

Figure 6.2: Absolute area of arable land in each district, and percentage of arable land in each district



Source: Author

Sector: Forest, Agriculture	**Vulnerability component:** Exposure	**Sub-component:** Social-system
Indicator: % employees in forest/agric. sector	**Measurement unit:** %	**Spatial and temporal scope:** District, once a year

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. The data set used for this indicator aggregates employers and employees working in the forest and agricultural sector. Data was originally collected from the Federal Office for Labour in Germany. The variable is an annual average.
Data type: Excel file

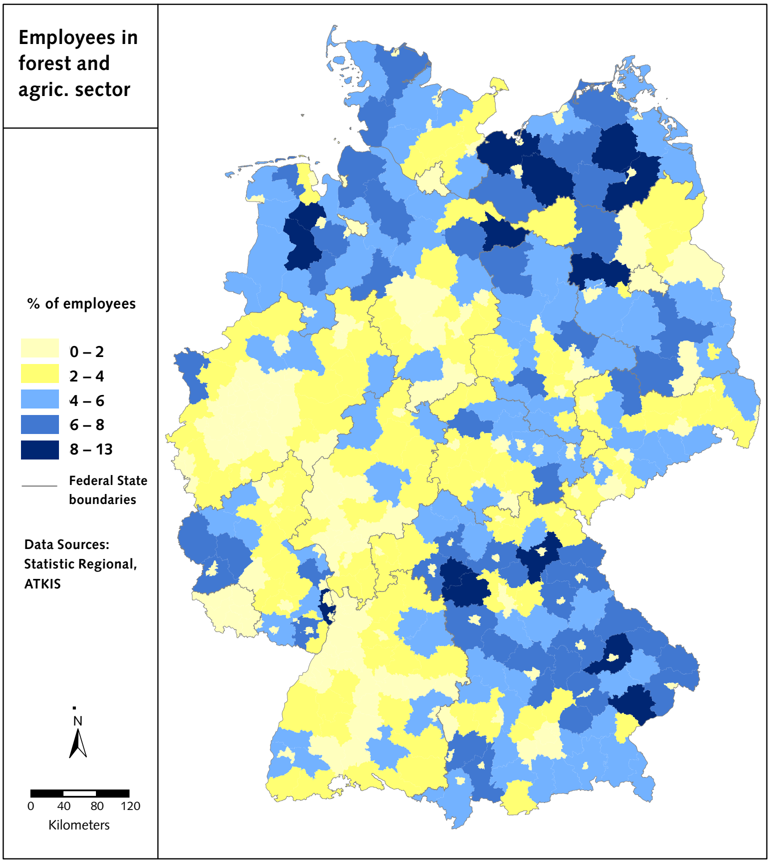
Technical note: The original data set 'number of employees in forestry, agriculture' per district has been transformed to a relative variable. The percentage of employees working in the respective sector per district was calculated in order to compare the results across all German districts and district-independent cities. Thus, the number of employees in the forest/agric. sector was divided by the total number of employees in a district.

Relevance: This indicator accounts for the fact that not only districts with a high rate of forested or farmland are exposed to the consequences of flooding, but also those with a high number of people working in the respective sector. For instance, in district-independent cities there are numerous employees who work in authorities or sector-related industries, but there is little forested area or farmland. Hence, this indicator considers elements of the social system that might be exposed in the case of flooding.

Validity: The data set is technically valid as it is collected once a year and contains actual information. However, the fact that no differentiated data exists for agriculture and forest needs to be taken into account. Data reflects only the number of employees for both sectors plus fisheries. However, after consulting various experts, the decision was made to use the data set anyway. Experts stated that there is a strong correlation between the number of workers in agricultural and forestry sectors. Farmers often own forests, and authorities in cities usually have agricultural and forest departments combined under one roof. As a comparison across Germany's districts is intended, the correlation is significant, not the exact value for each sector.

Visualization/Interpretation: In general the proportion of people working in agriculture and forestry in each district ranges between 0 and 13 %. Bavaria as well as east and north Germany show a high employee rate in both sectors. District-independent cities exhibit a very low rate because of their urban character. Baden-Württemberg, Hessen, and North Rhine-Westphalia show the lowest proportion of employees in the forest and agricultural sectors. Figure 6.3 shows both forest hot spots areas such as districts along the Rhine River in Baden-Württemberg and in the Eifel, as well as agriculture hot spots in north and east Germany.

Figure 6.3: Employees in forest and agricultural sector



Source: Author

Sector: Forest, Agriculture	**Vulnerability component:** Exposure	**Sub-component:** Social-system
Indicator: % gross value added	**Measurement unit:** %	**Spatial and temporal scope:** District, once a year

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. Gross value added of the respective sector is a measure of the economic output of a sector or service. The variable is an annual average.
Data type: Excel file

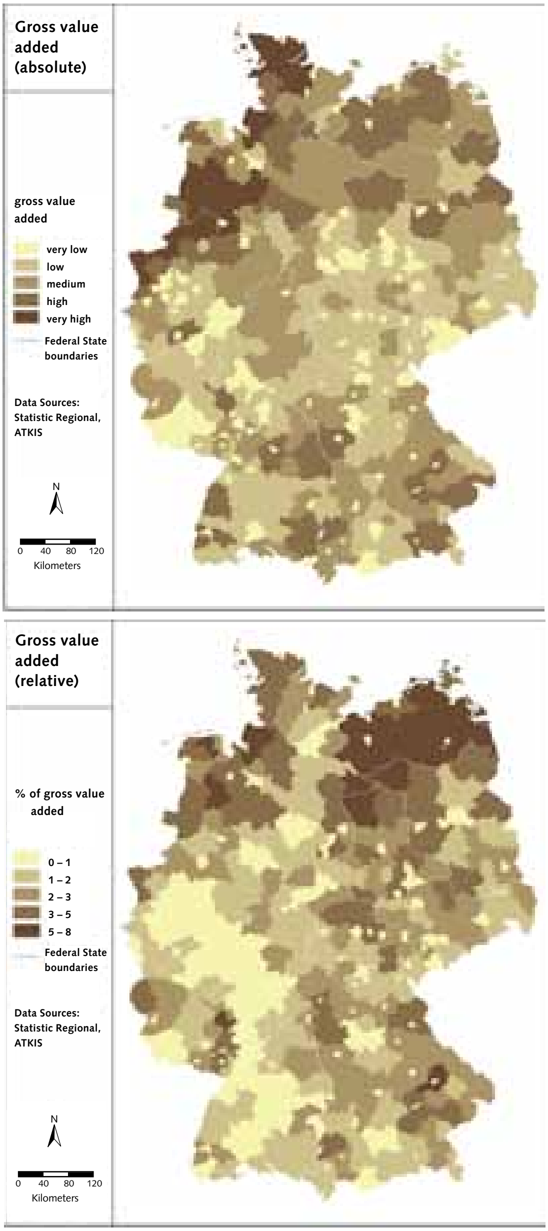
Technical note: The variable 'gross value added of forestry/agricultural sector' per district has been transformed to a relative variable. The proportion of the gross value added in the named sectors in comparison to the GDP in a district was calculated in order to compare the results across all German districts and district-independent cities. Thus, the gross value added of the forestry and agriculture sectors was divided by the total gross value added of a district.

Relevance: This indicator is an economic measure of the value of goods and services produced in a sector of an economy in a certain region. It is supposed to reflect the potential impact on the social system in the case of flooding. The assumption is that the higher the proportion of gross value added in a sector, the more exposed the economy of this region might become when production fails due to flooding. The economic dimension is addressed by this indicator.

Validity: The data set is technically valid, since it is collected once a year and contains actual information. However, it needs to be considered that no differentiated data exists for agriculture and forest. Data reflects only the gross value added for both sectors. However, after consulting various experts the decision was made to use the data set anyway. These experts confirmed a strong correlation between the gross value added of both sectors. As a comparison between Germany's districts is intended, the correlation is of great significance, not the exact value for each sector.

Visualization/Interpretation: The gross value added of the forest and agriculture sectors is high in the areas that are intensively used for forestry and agricultural purposes. In particular, the north-western districts in Germany show a very high gross value added. Central and western Germany exhibit very low to medium values. The proportion of the gross value added of the forestry and agriculture sectors shows a similar picture, as illustrated in figure 6.4. Thus, the indicators should be tested on correlations. In particular, the eastern parts and north-western parts of Germany have a high gross value added rate. By contrast, west Germany exhibits low values except for the regions 'Rheinhessen' and 'Pfalz', which are popular winegrowing areas.

Figure 6.4: Absolute and relative representation of gross value added of forest and agricultural sectors



Source: Author

Sector: Forest, Agriculture	**Vulnerability component:** Susceptibility	**Sub-component:** Social Condition
Indicator: Unemployment rate of district	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** District, once a year

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. Data collection took place in 2004. Data was originally collected from the Federal Office for Labour in Germany. The variable is an annual average.
Data type: Excel file

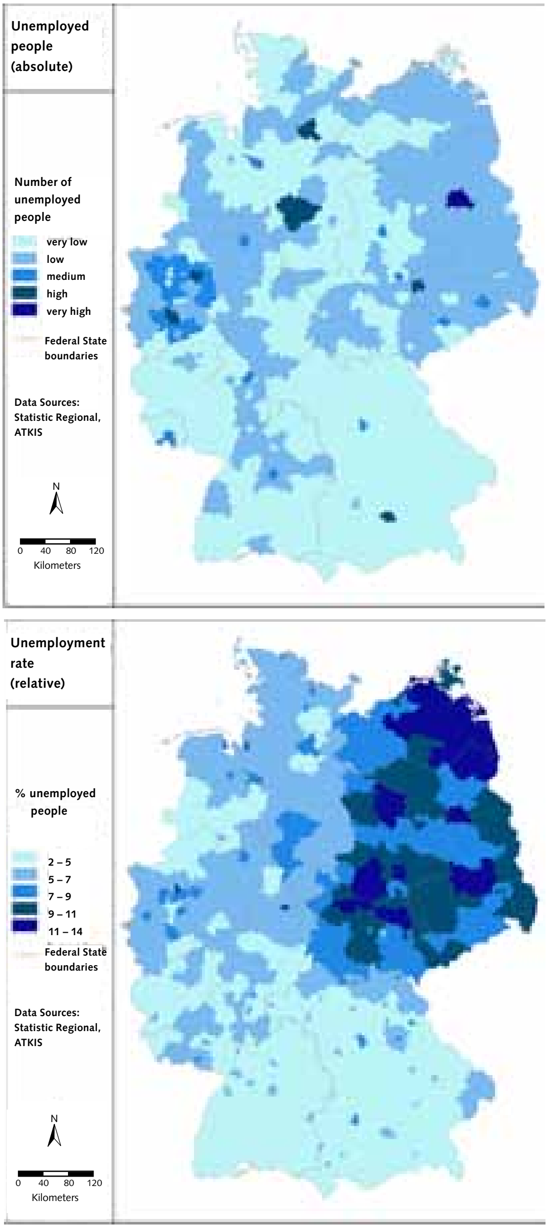
Technical note: The original data set 'number of unemployed people per district' has been transformed to a relative variable. The unemployment rate per district was calculated in order to compare unemployment across all German districts and district-independent cities. The unemployment rate was calculated by determining the proportion of unemployed people relative to the total labour force (which comprises both employed and unemployed people) in a district.

Relevance: The decline or loss of employment opportunities has strong implications for human well-being as well as a region's economy. Thus, the unemployment rate in a province is often used as an indicator of a region's economic and social susceptibility (Abraham et al. 1995; OECD 20006). High unemployment rates reflect overall low economic vitality. Unemployment rates also indicate the extent of economic competitiveness and the state of well-being of a region in terms of its ability to supply and maintain infrastructure and services. Therefore, this indicator has been selected as the most appropriate measure to inform about the condition and susceptibility of the social system in a district.

Validity: Technical validity is high as data is available at district level and is regularly updated by the Federal Office for Labour. From the analytical perspective it has been acknowledged by several experts that unemployment rate is the most appropriate available data set that allows an insight into the economic and social state of a district.

Visualization/Interpretation: In German districts the unemployment rate ranges between 2 and 14 %. The highest number of unemployed people can be found in large cities such as Munich and Berlin, as well as in the 'Ruhr Area' in North Rhine Westphalia. Altogether, Bavaria shows the lowest number of unemployed people. By mapping the unemployment rate of districts a different picture emerges. East Germany has the highest unemployment rate in a Germany-wide comparison. No district has a rate below 7 %. This development can be traced back to the division and reunification of Germany (see Chapter 2) that led to strong economic and social inequalities between west and east Germany. Further hot spots are found in the 'Ruhr Area' where the closing of numerous industrial and mining sites led to a high unemployment rate. The main parts of Bavaria and Baden-Württemberg show very low percentages of unemployed people. Figure 6.5 illustrates that only the region 'Bavarian Forest' in east Bavaria and the northern districts of Bavaria come up with percentages between 5 and 9 %, since these rural regions are weakly developed, especially in the secondary and tertiary sectors.

Figure 6.5: Number of unemployed people and unemployment rate in German districts



Source: Author

Sector: Forest	**Vulnerability component:** Susceptibility	**Sub-component:** Ecological Condition
Indicator: % damaged forest	**Measurement unit:** %	**Spatial and temporal scope:** Federal state, once a year

Data source:
Report on the state of German forests, Federal Ministry of Food, Agriculture and Consumer Protection 2006

Data description: Each federal state publishes an annual report on the state of its forests. The state of the forests is judged by means of a consistent Germany-wide damage classification.
Damage class 0 = 0-10 % loss of leaves and needles = no visible crown defoliation
Damage class 1 = 11-25 % loss of leaves and needles = slight crown defoliation
Damage class 2 = 26-60 % loss of leaves and needles = strong crown defoliation
Damage class 3 = 61-99 % loss of leaves and needles = very strong crown defoliation
Damage class 4 = 100 % loss of leaves and needles = dead
Data type: Excel file

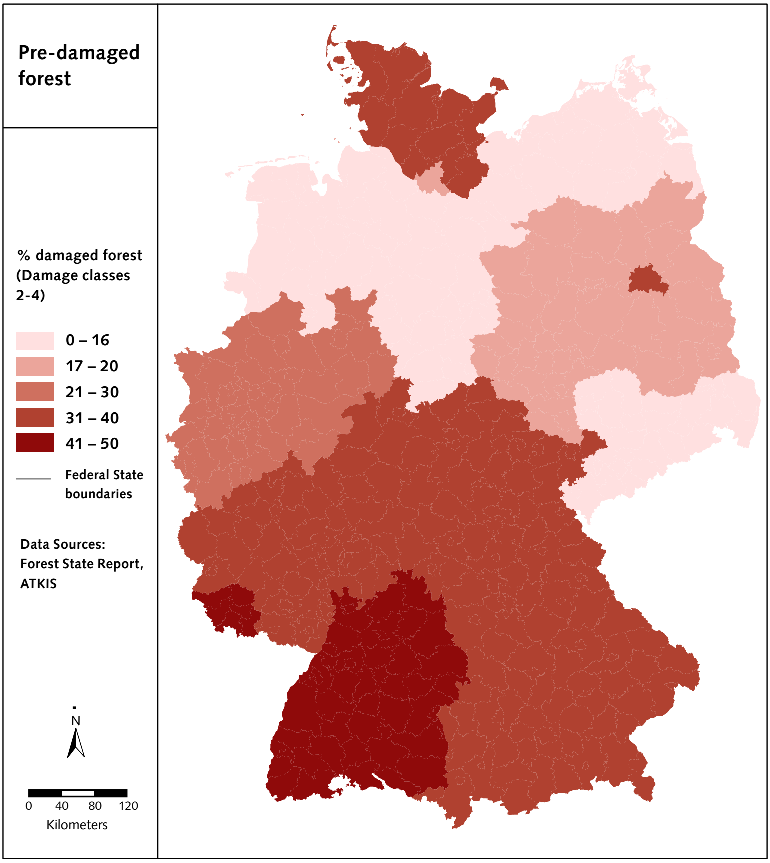
Technical note: For this indicator, the damage classes 2 and above have been selected to represent forest that is considerably damaged. The variable represents the percentage of damaged forest area (classes 2 - 4) in a federal state. The data have been disaggregated to district level by assigning equal values to each district or district-independent city.

Relevance: This indicator reports on damage and stress in forest ecosystems. Insect diseases, forest fires, or heavy machinery damage forest ecosystems and thus augment their susceptibility to upcoming hazards.

Validity: Technical validity is constrained due to the coarse resolution of data. Information about forest damage is only available at federal state level. This means that data has to be disaggregated to district level, which is done by the simple technique of assigning equal values to each district. The consequence is a significant loss of information. Therefore, this indicator can only be understood as a trend indicator. Due to its high relevance, the indicator was still accepted at the present level. Other data sets exist that describe the state of forest ecosystems with a higher/better resolution. However, this data is not available nationwide and methodology is not consistent.

Visualization/Interpretation: Figure 6.6 shows the percentage of damaged forest with at least ‘strong crown defoliation’ (damage class 2). Baden-Württemberg and Saarland exhibit the highest crown defoliation with 40-50 % damaged forests. The lowest damage rate is shown in the federal states Saxony, Lower Saxony, and Mecklenburg-Vorpommern. The main causes of crown defoliation are the emission of SO2 and NOX and their impacts on forest ecosystems (BMELV 2006). Moreover, a significant increase of O3 has been measured at numerous control points. The summer of 2003 was characterized by a long and intense drought. The consequences can still be measured in German forests today.

Figure 6.6: Mean crown defoliation in federal states



Source: Author

Sector: Forest, Agriculture	**Vulnerability component:** Susceptibility	**Sub-component:** Ecological Condition
Indicator: Water quality index	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** Polygons of all major river systems, about every five years

Data source:
Biologische Gewässergüte (Biological water quality), LAWA 2006

Data description: Each federal state has the obligation to monitor the biological and chemical water quality of its major rivers. The data is collected by the German Working Group on Water Issues of the federal states and the Federal Government (LAWA), and is published in the Water Quality Atlas approximately every five years. Water quality is determined using a consistent methodology across all federal states. Hence, several biological and chemical characteristics are measured and used to evaluate the quality of surface water in rivers. Quality classes are then assigned to river stretches. The following classes exist: I = unpolluted or very slightly polluted, I - II = slightly polluted, II = moderately polluted, II—III = critically polluted, III = seriously polluted, III—IV = very seriously polluted, IV = excessively polluted
Data type: Shape file

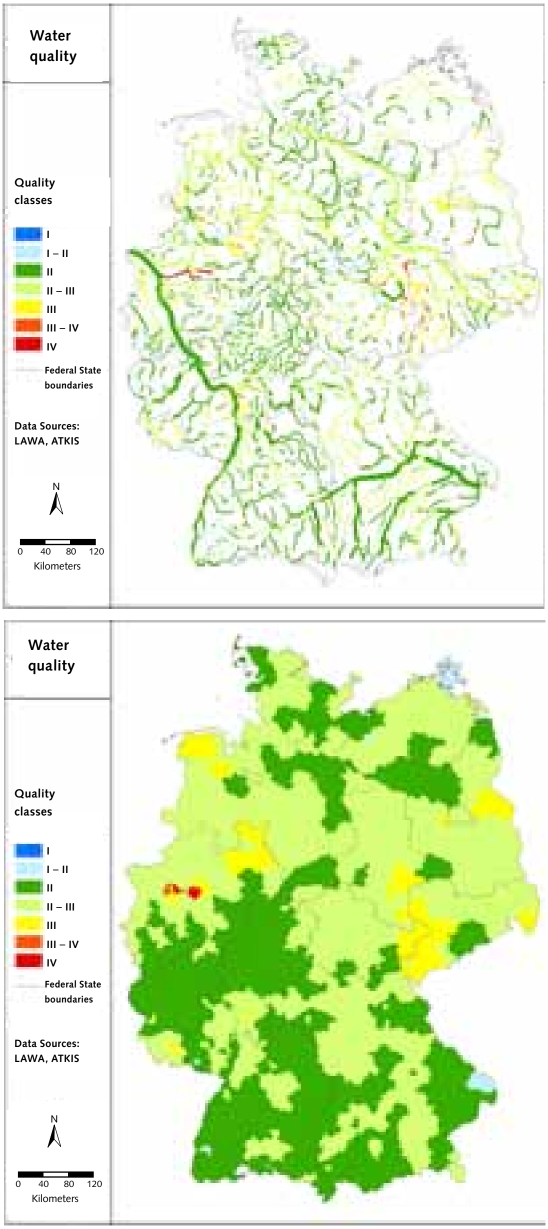
Technical note: A GIS shape file served as the basis for all calculations. The shape file contained polygons with a certain status (quality class) for each river stretch. Rivers of the 1st and 2nd order were captured. Rivers of the 1st order are represented by broader river stretches than rivers of the 2nd order in the original data set to emphasize the stronger influence on the environment. As one district contains numerous river stretches, data had to be aggregated. Therefore, a medium value was calculated for each district by calculating the area of each river stretch polygon and multiplying it with its quality class. These values were summed up for each district and divided by the sum of the total area of river stretches. By conducting an area calculation the dominant influence of large rivers can be considered.

Relevance: The biological water quality informs about the status of surface water. Surface water quality is influenced by the input of organic and inorganic substances, waste water, and waste heat triggered or caused by different human activities. In industrial areas the amount of inorganic and organic substances is usually very high (Geller et al. 2004). Thus, this indicator reports about the potential of contamination during a flood event when river water enters the floodplains and, moreover, indicates the pressure and stress the ecological system is already facing.

Validity: The validity of this indicator is constrained by the aggregation of data to district level. This implies substantial loss of information. However, due to its high relevance the indicator was approved by the experts. The fact that rivers of the 1st and 2nd order are captured in the data set has to be considered as well. Rivers of the 1st order have been given a higher priority in the calculation procedure.

Visualization/Interpretation: The water quality of German rivers ranges between unpolluted/very slightly polluted, and excessively polluted (see Figure 6.7). The major rivers Danube, Rhine, Elbe, Weser, Oder, and Main exhibit quality classes of II and II-III. Only the small rivers of the 2nd order have a poorer water quality. These are, for instance, the Rhine-Herne Canal in North Rhine Westphalia which crosses the ‘Ruhrgebiet’, and the Weiße Elster and Mulde in Saxony which originate in the ‘Ore Mountains’. Although the water quality of German rivers has been constantly improved in past years, rivers still have a poor quality in industrial areas and in regions with mining industries and chemical production. The Elbe is still critically polluted, which is partly because the river traverses two countries before entering Germany.

Figure 6.7: Biological water quality of German rivers of the 1st and 2nd order, and mean water quality calculated for each district



Source: Author

Sector: Agriculture	**Vulnerability component:** Susceptibility	**Sub-component:** Ecological Condition
Indicator: Erodibility	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** Scale 1:1,000,000, regular updates

Data source:
SGDBE, Joint Research Centre, Institute for Environment and Sustainability 2006

Data description: The Soil Geographical Database of Europe (SGDBE) at Scale 1:1,000,000 is part of the European Soil Database. It is the result of a collaborative project involving all the European Union and neighbouring countries. The database contains a list of Soil Typological Units (STUs). Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils: for example the texture, the water regime, etc. The geographical representation was chosen at a scale corresponding to 1:1,000,000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into Soil Mapping Units (SMUs) to form soil associations and to illustrate the functioning of pedological systems within the landscapes. The database also includes soil erodibility information. Crusting, parent material, and physical/chemical factors are deduced from the soil characteristics using chained pedotransfer rules, facilitating the calculation of the soil erosion potential. Erodibility is divided into the following classes: 1 = very weak, 2 = weak, 3 = moderate, 4 = strong, 5 = very strong.
Data type: Excel and Shape files

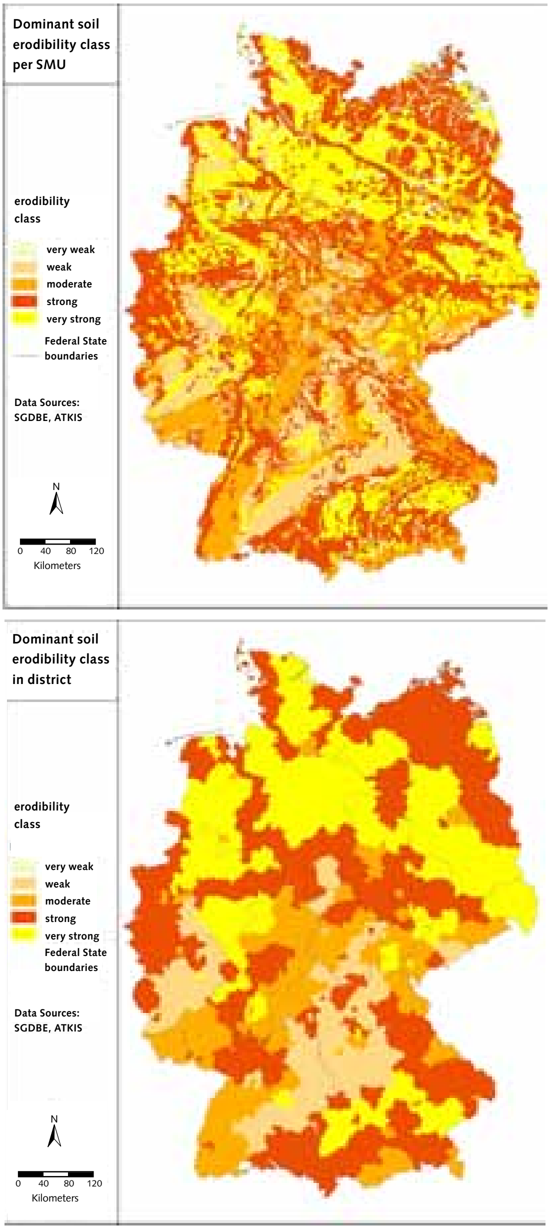
Technical note: The soil erodibility factor was originally assigned to an STU. Thus, the first step was to up-scale it to the next higher level, which is the SMU. Maximum, minimum, and median values were produced during this procedure. The median value was calculated by first summing up the products of the proportion of STU area in an SMU and the respective erodibility class. Then this value was divided by the sum of all proportions. Subsequently, the dominant soil erodibility class for each district had to be determined. Therefore, the surface ratio of each class in a district was calculated. Then, the erodibility class with the highest ratio was selected and applied to each district. The original ordinal categories/ranks were adopted for the approach. The calculations were conducted in GIS and with a statistical program. Missing values have been interpolated by assigning the average value of the neighbouring STUs.

Relevance: Agricultural soil erosion reduces soil quality and degrades water quality. Even relatively small movements cause changes in soil structure that can reduce fertility and make normal cropping practices difficult. By removing the most fertile topsoil, erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of natural farmland. Even where soil depth is good, loss of the topsoil is often not conspicuous but nevertheless potentially very damaging. The potential for soil erosion depends on several factors such as soil characteristics, land use, and land cover. This indicator refers to the inherited potential of soils to be susceptible to erosion at a certain place. Thus, the indicator serves as a proxy to assess overall soil erosion potential.

Validity: The validity of this indicator is constrained by the aggregation of data from STU to district level. This implies substantial loss of information. Furthermore, the indicator acts only as a proxy for the assessment of soil erosion potential as it considers only one aspect within the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). However, the indicator facilitates the assessment of regional hot spots with special regard to soil properties. If a local analysis or a regional analysis with a small geographical scope is conducted, it is recommended to use soil data produced by the federal states. Usually, these data sets exhibit a higher spatial resolution. However, these soil maps are not free of charge and do not exhibit a consistent cross-state methodology.

Visualization/Interpretation: The mapping of erosion classes reveals quite a heterogeneous picture across Germany (see Figure 6.8). In particular, the glacially shaped regions in south and north Germany that have low relief energy exhibit high erodibility classes. By contrast, the mountainous regions in central Germany as well as the south German ‘Schichtstufen Land’ are characterized by weak and moderate soil erosion potential. These patterns are also reflected in the representation of soil erodibility classes per district.

Figure 6.8: Soil erosion classes at Soil Mapping Units and at district level



Source: Author

Sector: Agriculture	**Vulnerability component:** Susceptibility	**Sub-component:** Ecological Condition
Indicator: Contamination potential	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** 1:250,000, regular updates at least once a year

Data source:
ATKIS, Federal Agency for Cartography and Geodesy, 2007

Data description: On the basis of an administrative agreement with the federal states the Federal Agency for Cartography and Geodesy provides for area-wide coverage harmonized basic geodata of the "Official Topographic-Cartographic Information System" (ATKIS) and distributes this data. ATKIS contains a huge amount of object information such as infrastructure, land cover, buildings, protected areas etc. For this indicator, Level Sie05F data has been acquired. From Level Sie05F six objects have been identified as potential contaminating sources. The objects are: mining sites, dump sites, refineries, sewage plants, conveyer systems, and waste treatment plants. Unlike other data sets, this one is not free of charge.
Data type: Shape files

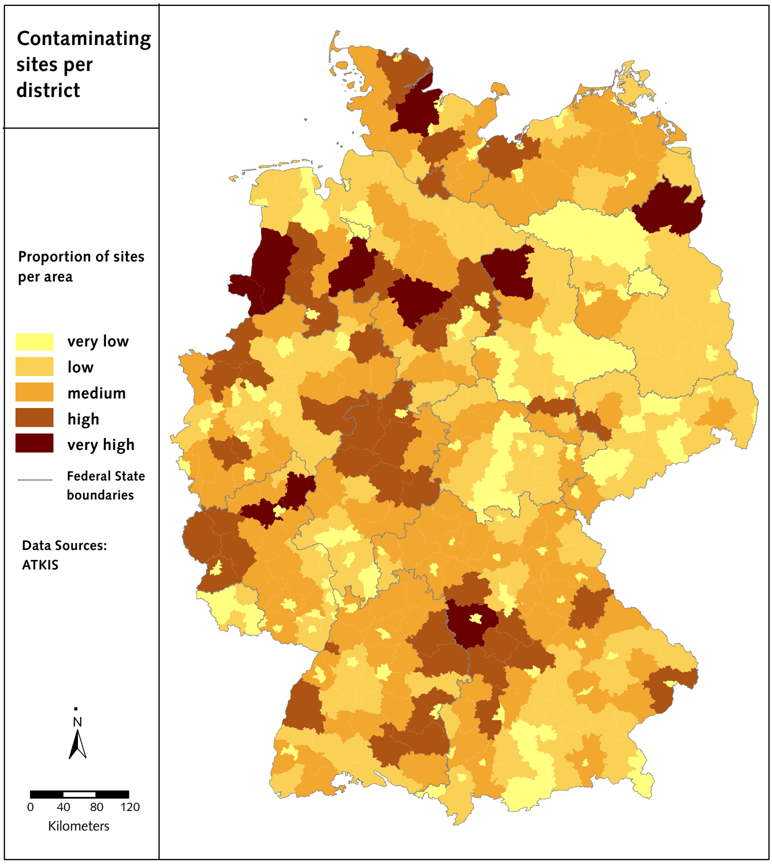
Technical note: In a GIS the number of objects per district area is calculated by intersecting districts with the object file, counting the entries in a district, and dividing the number by the total land area of the district. Thus a relative value was created which is necessary in order to compare the result across all districts in Germany.

Relevance: Pollution may result from a wide range of human activities and can emanate either from local sources or from diffuse sources, causing a deterioration or loss of one or more ecological functions (van Lynden 2000). Contamination exerts a significant pressure on the ecological system, causing changes and alteration of functions and processes. This indicator reports about the potential for contamination at a certain place because of the existence of contamination sources. In the case of flooding, contamination typically arises from the rupture of oil tanks, application of pesticides, leaching of wastes from landfills, direct discharge of industrial wastes to the soil, or the flooding of sewage plants. Often, the occurrence of this phenomenon is correlated with the degree of industrialization and chemical usage in a region.

Validity: The number of potentially dangerous sites is an important issue that must be considered in the approach. However, it has to be acknowledged that no information exists whether these sites are protected against flooding. Moreover, only a small selection of sites is captured by the available data set. For instance, chemical industry and abandoned military exercise fields are not included. Thus, this indicator cannot provide exact measures of contamination but indicates a certain potential of contamination. As abandoned industrial sites are often sources of contamination, the data set ‘brownfield areas’ might be an additional data source. However, due to the lack of Germany-wide data access, this data could not be used. Pesticide spraying and other potential forms of diffuse pollution cannot be captured by this indicator either.

Visualization/Interpretation: Mapping the ratio of potential contaminating sites per district area reveals the existence of several hot-spots, especially in west Germany (see Figure 6.9). Numerous districts along the Rhine River such as Cologne, Karlsruhe, and Koblenz have a high rate of contaminating sites. Further hot spots have been mapped in the region of Leipzig and in the ‘Harz’. Large parts of central and east Germany as well as the most southern districts, on the other hand, show a low rate.

Figure 6.9: Contamination potential in districts



Source: Author

Sector: Forest	**Vulnerability component:** Capacities	**Sub-component:** Ecosystem robustness
Indicator: Forest size	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** Scale 1:100,000, update every few years.

Data source:
CORINE Land Cover; Federal Environmental Agency, DLR-DFD 2004.

Data description: In the project CORINE Land Cover, the mapping of land cover and land use was performed on the basis of satellite remote sensing images on a scale of 1:100,000. The first database, CLC1990, which was finalized in the 1990s, consistently provided land use information comprising 44 classes, out of which 37 classes are relevant to Germany. An update of land use information has been accomplished using the year 2000 as a reference. The project CLC2000 was led by the German Remote Sensing Data Centre of the German Aerospace Centre (DLR) on behalf of the Federal Environmental Agency. For this indicator, forest land cover data has been used from the CORINE data set.
Data type: Shape files

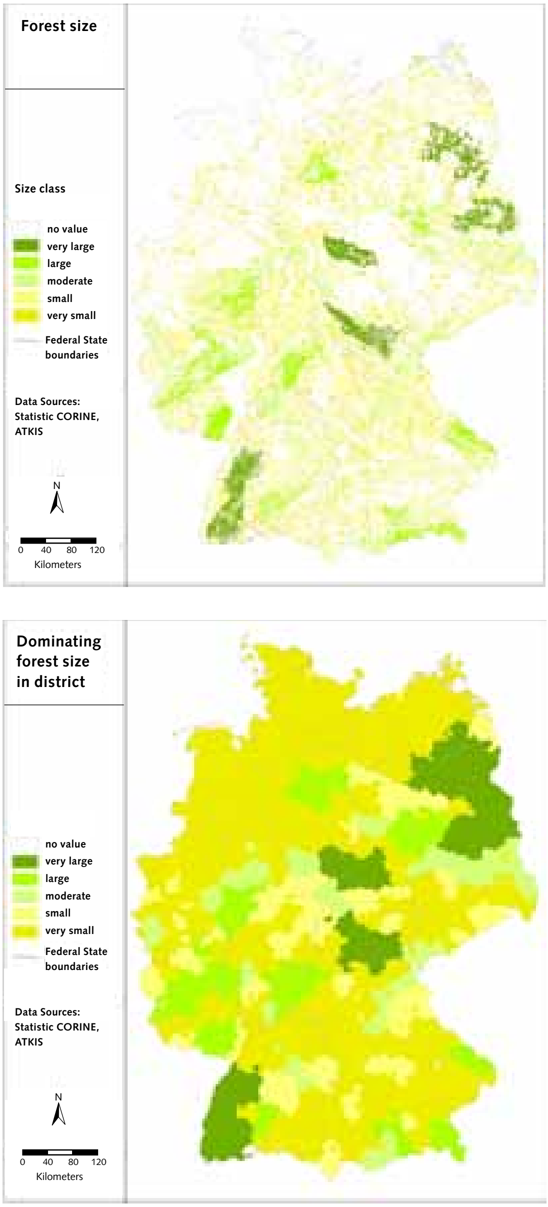
Technical note: The CORINE data set differentiates between the three different forest types coniferous, deciduous, and mixed. These have been aggregated first in GIS. Subsequently, the size of every forest (meaning interconnected forested areas) was calculated. Then the forests were grouped into different classes according to their size. 1 = 1800 km^2 - 4000 km^2, 2 = 800 km^2 – 1800 km^2, 3 = 300 km^2 – 800 km^2, 4 = 50 km^2 – 300 km^2, 5 = < 50 km^2. Finally, the dominant forest size class was assigned to the respective district by calculating the proportion of forest area for each size class in a district and selecting the dominant one.

Relevance: Forest size is a crucial aspect of the evaluation of forest health and integrity (Kapos et al. 2000). When forests are lost or severely degraded, their capacity to function as regulators of the environment is also constrained. This might lead to increasing flood and erosion hazards, thus reducing soil fertility and contributing to the loss of plant and animal life. As a result, the sustainable provision of goods and services from forests is jeopardized. Smaller forests usually support a lower diversity of forest-dwelling species and proportionally smaller numbers of each species due to edge effects, which can extend from 100 to 300 metres into the forest. “Patches of 200 hectares are considered the minimum size for a forest ecosystem to recover from disturbance events such as wind-throw, fires, or insect and disease infestations” (Rusak 2003: 3).

Validity: The indicator is regarded as sufficiently valid. However, some technical constraints are implied. The indicator is an ordinate variable as different size classes are represented. Those classes have been assigned through the natural breaks function in ArcGIS. This is due to the fact that no consistent classification scheme could be identified from literature. Furthermore, forest size has been calculated in GIS by using the DISSOLVE function. However, the calculated size is probably not identical to the actual one as forest data is mapped and classified by means of remote sensing data which is impaired by uncertainties associated with the resolution of the satellite images and the applied classification technique. In this case the smallest cell size is 25 ha. This means that small corridors between forest ecosystems cannot be mapped. However, those small transition zones can be ignored as they are small enough to be easily bridged by fauna and flora.

Visualization/Interpretation: In figure 6.10, different size classes are assigned to forest ecosystems in Germany. The largest connected forest areas in Germany lie in the Black Forest, the Eifel, the Sauerland, the Thüringer Forest, the Harz, and in the district around Berlin. These regions are predominantly mountainous, except for the flat, glacially shaped plains in the north-east. However, most areas in Germany exhibit strongly fragmented and small-sized forest ecosystems.

Figure 6.10: Forest size classes



Source: Author

Sector: Forest	**Vulnerability component:** Capacities	**Sub-component:** Ecosystem robustness
Indicator: Forest type	**Measurement unit:** %	**Spatial and temporal scope:** Scale 1:100,000, update every few years.

Data source:
CORINE Land Cover; Federal Environmental Agency, DLR-DFD 2004

Data description: In the project CORINE Land Cover the mapping of land cover and land use was performed on the basis of satellite remote sensing images on a scale of 1:100,000. The first database, CLC1990, which was finalized in the 1990s, consistently provided land use information comprising 44 classes, out of which 37 classes are relevant to Germany. An update of land use information has been accomplished using the year 2000 as reference. The project CLC2000 was led by the German Remote Sensing Data Centre of the DLR on behalf of the Federal Environmental Agency. For this indicator, forest land cover data has been used from the CORINE data set.
Data type: Shape files

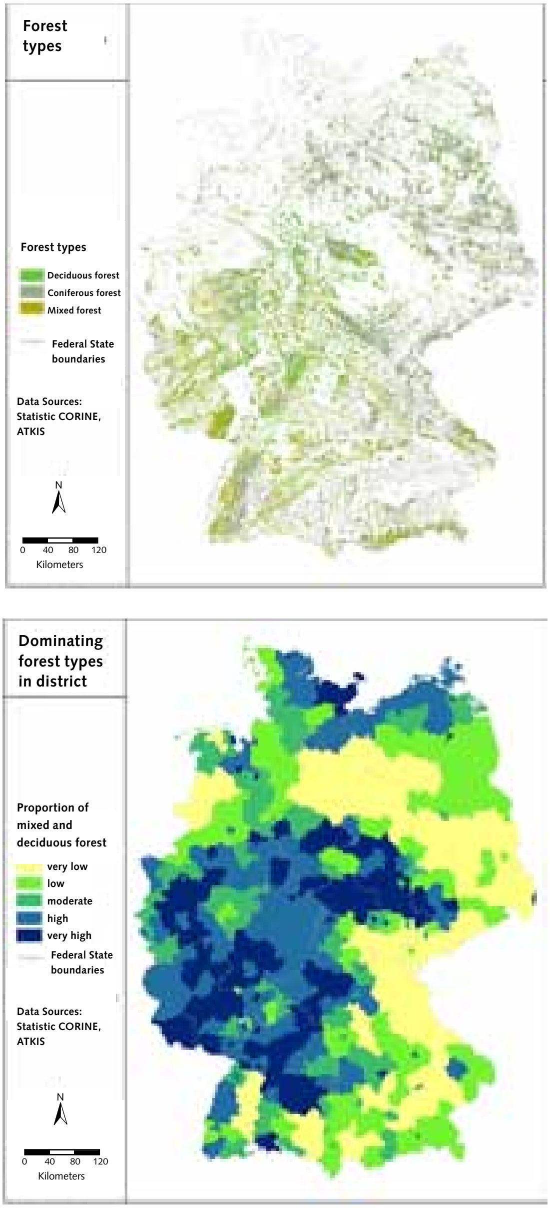
Technical note: The CORINE data set differentiates between three different forest types: Mixed, coniferous, and deciduous forest. For this indicator, the percentage of mixed+deciduous forests in a district has been calculated. Therefore, the proportion of each forest type per district was determined. Subsequently, the percentages of mixed and deciduous forest were summed up.

Relevance: The indicator 'forest type' reports the percentage of flood-tolerant tree species in a district. As discussed in the previous chapter, tree species react differently to river flooding. Some tree species are, for instance, more tolerant to anaerobe conditions than others. The analysis of the Potential Natural Vegetation Map (PNV) of Germany reveals which tree species typically grow in German river floodplains. Moreover, the analysis of already conducted studies on flood tolerance of forests and tree species showed that deciduous tree species such as ash and willow are particularly well adapted to flood conditions. By contrast, coniferous species do not typically exist in river floodplains apart from on high, sandy river terraces. Scherer-Lorenzen et al. (2005) showed that healthy forest ecosystems usually exhibit a high diversity of species and then show a high potential to withstand and resist a disturbance. Thus, it is not only the deciduous but also the mixed forest ecosystems that contribute to high ecosystem robustness. Therefore, the percentage of deciduous and mixed forest ecosystems has been selected to indicate the degree to which a forest might resist or adapt to flooding.

Validity: The indicator is sufficiently valid but has some major constraints. Only the three classes of forest types from the CORINE database are used to describe the dominant forest type in a region. More detailed information was unfortunately not obtainable for the whole of Germany. Thus, information content is quite poor. This aggravates the assessment of flood-tolerant forest types. However, the indicator is of high relevance and still provides a valuable overview of hot spot areas in Germany. This is why the indicator was approved by the experts.

Visualization/Interpretation: The percentage of mixed and deciduous forests per district is very high in central and west Germany (see Figure 6.11). By contrast, in the south-eastern and north-eastern parts of Germany, districts exhibit a low to very low rate of mixed and deciduous forests. Only in the coastal areas in north Germany were higher rates of flood tolerant forest types mapped. The high rate of coniferous species (especially pines and spruces) in different parts of Germany can be traced back to the transformation of forest ecosystems to economically cultivated forests in past centuries.

Figure 6.11: Forest types in Germany and proportion of flood-tolerant forest types in German districts



Source: Author

Sector: Forest	**Vulnerability component:** Capacities	**Sub-component:** Ecosystem robustness
Indicator: Forest fragmentation	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** Scale 1:100,000, update every few years.

Data source:
CORINE Land Cover; Federal Environmental Agency, DLR-DFD 2004.

Data description: In the project CORINE Land Cover the mapping of land cover and land use was performed on the basis of satellite remote sensing images on a scale of 1:100,000. The first database, CLC1990, which was finalized in the 1990s, consistently provided land use information comprising 44 classes, out of which 37 classes are relevant to Germany. An update of land use information has been accomplished using the year 2000 as a reference. The project CLC2000 was led by the German Remote Sensing Data Centre of the DLR on behalf of the Federal Environmental Agency. For this indicator, forest land cover data has been used from the CORINE data set.
Data type: Shape files

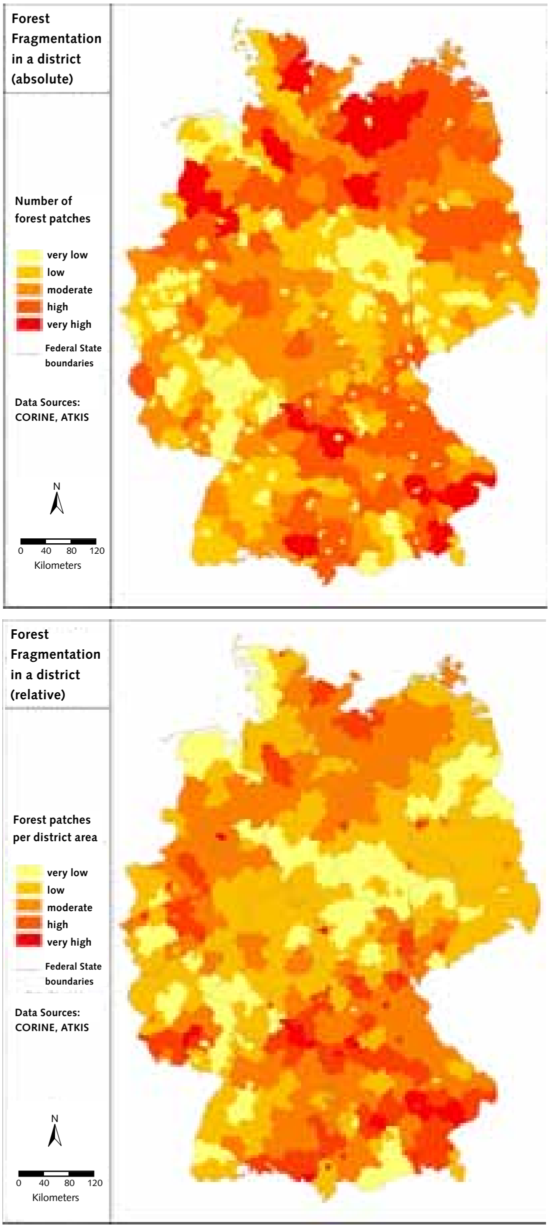
Technical note: This indicator is based on the indicator ‘forest size’. The calculation draws on the idea that many small forest patches indicate a high degree of forest fragmentation. Thus, the indicator is determined by the number of small forest patches in a district. The number of small forest patches in a district was counted by a Pivot calculation in a statistical program and was then divided by the land area of a district to make the outputs comparable across districts.

Relevance: Forest fragmentation is a crucial aspect of the state of forest ecosystems (Kupfer 2006). Forest loss and fragmentation result in a range of ecological, environmental, social, and economic impacts. Three distinct changes in forest ecosystem pattern accompany forest conversion: reduced forest area, increased isolation of resulting remnants, and creation of edges where remnant forest abuts modified ecosystems. “Removal and fragmentation of forests has thus been cited as one of the greatest causes of biotic impoverishment worldwide” (Kupfer 2006: 74). Hence, forest fragmentation is an appropriate indicator to assess the degree of ecosystem functioning and well-being; factors which have to be considered when assessing ecosystem robustness.

Validity: The indicator is valid in a technical and analytical sense. The only constraint is that the method of fragmentation calculation does not distinguish between fragmentation caused by human activity and the natural patchwork of forest and non-forest cover. Moreover, very small forest patches are not captured because of the resolution of remote sensing images. The method used in this approach is based on simple GIS calculation techniques. Different, complicated approaches using the ‘Neighbourhood technique’ can be found in literature (e.g. The Heinz Centre for Science Economics and the Environment 2002).

Visualization/Interpretation: The distribution of forest fragmentation in districts is quite different throughout Germany. In the northern and the southern parts of Germany, districts with the highest degree of fragmentation prevail. Central and west Germany show high connectivity of forest ecosystems. The relative forest fragmentation map shows a slightly different picture. In particular, urban areas exhibit a very high fragmentation rate of forest ecosystems. Further hot spots are mapped in the south-eastern part of Bavaria, in the Main-Tauber district in north-west Baden-Württemberg, in the Saarland, and in the ‘Ruhr Area’ (see Figure 6.12).

Figure 6.12: Absolute and relative forest fragmentation per district



Source: Author

Sector: Agriculture	**Vulnerability component:** Capacities	**Sub-component:** Ecosystem robustness
Indicator: Water storage capacity - Texture	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** Scale 1:100,000, regular updates

Data source:
SGDBE, Joint Research Centre, Institute for Environment and Sustainability 2006

Data description: The SGDBE at Scale 1:1,000,000 is part of the European Soil Database. It is the result of a collaborative project involving all the European Union and neighbouring countries. The database contains a list of STUs. Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils, for example the texture, the water regime, the stoniness, etc. The geographical representation was chosen at a scale corresponding to 1:1,000,000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into SMUs to form soil associations and to illustrate the functioning of pedological systems within the landscapes. Soil texture is used as a proxy to assess the water retention capacity of soils. The SGDBE contains information on texture in the form of ordinal texture classes. 1 = coarse (18% <clay and > 65% sand), 2 = medium (18<clay < 35% and >= 15% sand, or 18% < clay and 15% < sand < 65%), 3 = medium fine (<35% clay and <15% sand), 4 = fine (35% < clay <60%), 5 = very fine (clay > 60%)
Data type: Excel and Shape files

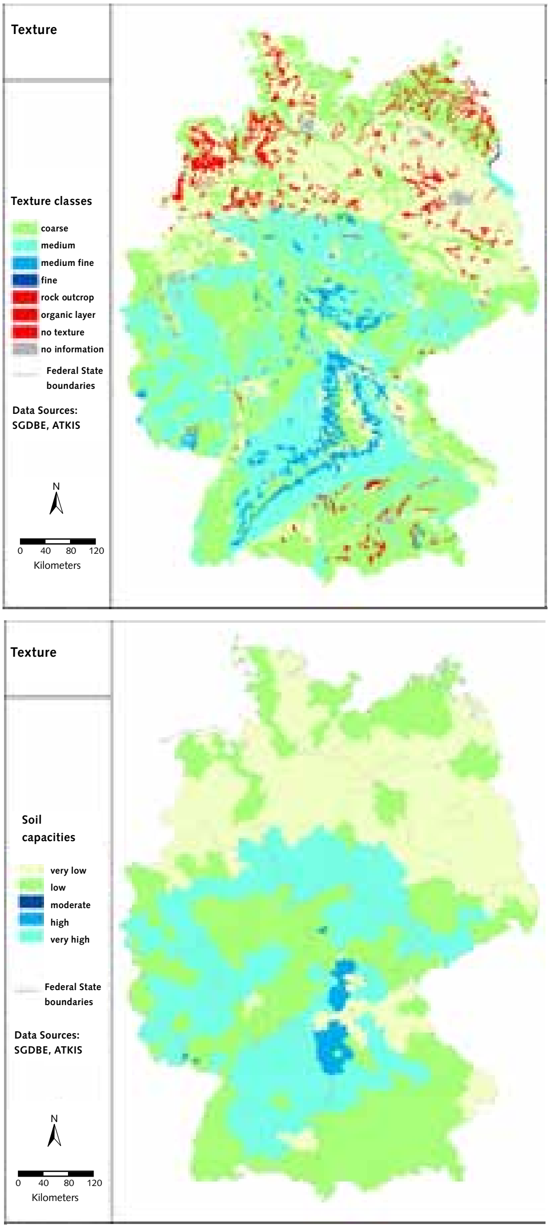
Technical note: The texture values were originally assigned to an STU. Thus, the first step was to up-scale texture to the next level, which is the SMU. Maximum, minimum, and median values were produced during this procedure. The median value was calculated by first summing up the products of the proportion of STU area in an SMU and the respective texture class. Then this value was divided by the sum of all proportions. Subsequently, the dominant texture class for each district had to be calculated. Therefore, the proportion of land area of each class in a district was determined. Then, the texture class with the highest ratio was selected and applied to each district. Finally, the texture classes had to be ranked with regard to their capacity to filter and buffer or retain water. Therefore, the original values were substituted by the following ordinal values: 1 1, 2 2, 5 3, 4 4, 3 5 (means substituted). The calculations were conducted in GIS and with a statistical program. Missing values have been interpolated by assigning the average value of the neighbouring STUs.

Relevance: Soil texture influences many other soil properties that are of great significance to land use and management such as organic matter content, native fertility, water retention, nutrient retention, cation exchange and buffer capacities, and permeability to water and air. Sandy soils tend to be low in organic matter content and native fertility, low in ability to retain moisture and nutrients, low in cation exchange and buffer capacities, and rapidly permeable, whereas finer-textured soils generally are more fertile, contain more organic matter, have higher cation exchange and buffer capacities, are better able to retain moisture and nutrients, and permit less rapid movement of air and water. When soils are classified as clayey, however, they are likely to exhibit properties which are somewhat difficult to manage or overcome. Such soils tend to silt up under wet conditions.

Validity: The validity of this indicator is constrained by the aggregation of data from STU to district level. This implies substantial loss of information. However, due to its high relevance the indicator was approved by the experts. The indicator can at least provide a rough picture of where regional hot spots exist. If a local analysis or a regional analysis with a small geographical scope is conducted, it is recommended to use soil data collected and published by the federal states as their database has a finer resolution. ‘Field capacity’ can alternatively be used as indicator to describe the water retention capacity of soils.

Visualization/Interpretation: Figure 6.13 shows that large parts of west and central Germany exhibit the texture class ‘medium fine’ (rank = ‘very high’) which has been classified as the most favourable class in terms of water storage capacity as well as filter and buffer capacity. South of the river Danube and in the mountainous regions of central Germany the dominant texture classes are no higher than the class ‘low’. The glacially shaped landscape of north Germany is mainly dominated by coarse and medium textures as well as by soils without any texture. These are usually peat soils or organic layers that exist in the lowland moors and marshes of Mecklenburg-Vorpommern, Lower Saxony, and Bavaria.

Figure 6.13: Texture class of Soil Mapping Units and dominant texture classes in districts



Source: Author

Sector: Agriculture	**Vulnerability component:** Capacities	**Sub-component:** Ecosystem robustness
Indicator: Filter and buffer capacity – OCC	**Measurement unit:** Non-dimensional	**Spatial and temporal scope:** Scale 1:100,000, regular updates

Data source:
SGDBE, Joint Research Centre, Institute for Environment and Sustainability 2006

Data description: The SGDBE at scale 1:1,000,000 is part of the European Soil Database. It is the result of a collaborative project involving all the European Union and neighbouring countries. The database contains a list of STUs. Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils, for example the texture, the water regime, the stoniness, etc. The geographical representation was chosen at a scale corresponding to 1:1,000,000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into SMUs to form soil associations and to illustrate the functioning of pedological systems within the landscapes. The SGDBE contains information on 'Topsoil Organic Carbon (OC) Content' in form of ordinal classes: 1 = very low (<1%), 2 = low (1-2%), 3 = medium (2-6%), 4 = high (> 6%).
Data type: Excel and Shape files

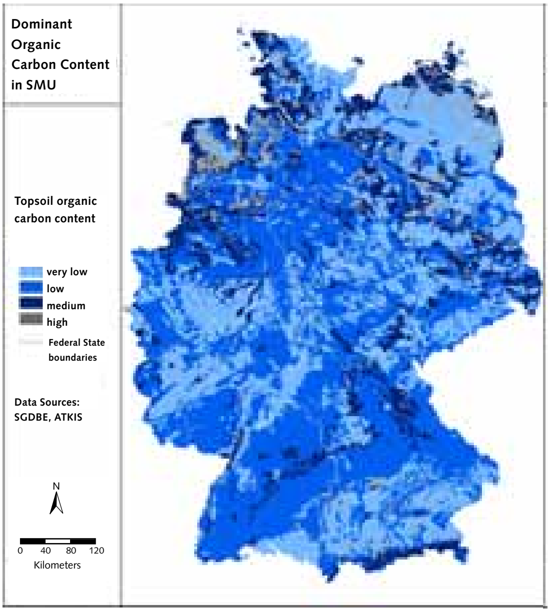
Technical note: The category of organic carbon content (OCC) was extracted from the database. The OCC values were originally assigned to a STU. Thus, the first step was to up-scale the OCC to the next level, which is the SMU. Maximum, minimum, and median values were produced during this procedure. The median value was calculated by first summing up all the products of the proportion of STU area in a SMU and the respective OCC class. Subsequently, the dominant OCC class for each district had to be calculated. Therefore, the surface ratio of each class in a district was determined. Then, the OCC class with the highest ratio was selected and applied to each district. The original ordinal categories/ranks were adopted for the approach. The calculations were conducted in GIS and with a statistical program. Missing values have been interpolated by assigning the average value of the neighbouring STUs.

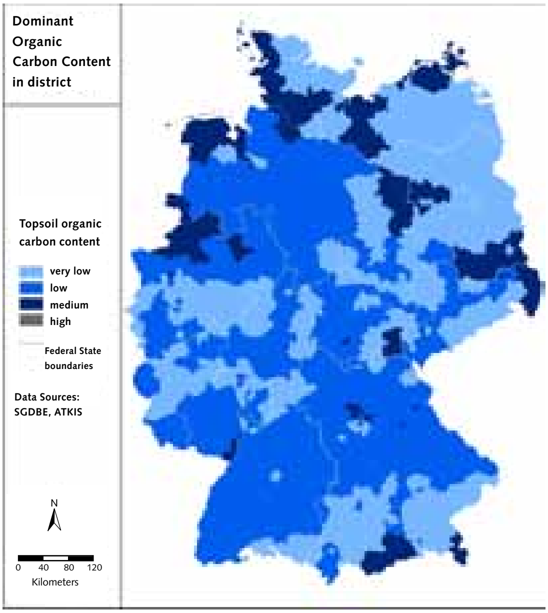
Relevance: Soil organic carbon, the major component of soil organic matter, is extremely important for all soil processes. Organic matter is an important 'building block' for soil structure and for the formation of stable aggregates (Beare et al. 1994; Oades and Waters 1991). Other benefits are related to the improvement of infiltration rates and the increase in storage capacity for water. Furthermore, OC serves as a buffer against rapid changes in soil reaction (pH) and acts as an energy source for soil micro-organisms. Without OC, biochemical activity in soil would effectively be negligible. Additionally, it supplies nutrients and also protects against erosion.

Validity: The validity of this indicator is constrained by the aggregation of data from STU to district level. This implies substantial loss of information. However, due to its high relevance the indicator was approved by the experts. The indicator can at least provide a rough picture of where regional hot spots exist. If a local analysis or a regional analysis with a small geographical scope is conducted, it is recommended to use soil data collected and published by the federal states as their database has a finer resolution. 'Field capacity' can alternatively be used as indicator to describe the water retention capacity of soils.

Visualization/Interpretation: OCC exhibits medium to high values in the lowland and upland moors in the alpine and coastal regions (see Figure 6.14). The amount 1-2 % OCC in top soils appear most frequently in Germany. Top soils with 'very low' OC content exist, especially in the southern parts of Bavaria, in west Germany and in north-eastern Germany.

Figure 6.14: Organic carbon content of Soil Mapping Units and dominant Organic Carbon Content class per district





Source: Author

Sector: Agriculture	**Vulnerability component:** Capacities	**Sub-component:** Ecosystem robustness
Indicator: % grasslands/pastures	**Measurement unit:** %	**Spatial and temporal scope:** District, every two years

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be output on state, provincial, and district level. The variable 'permanent grasslands' is part of the agricultural land use information provided every two years.
Data type: Excel file

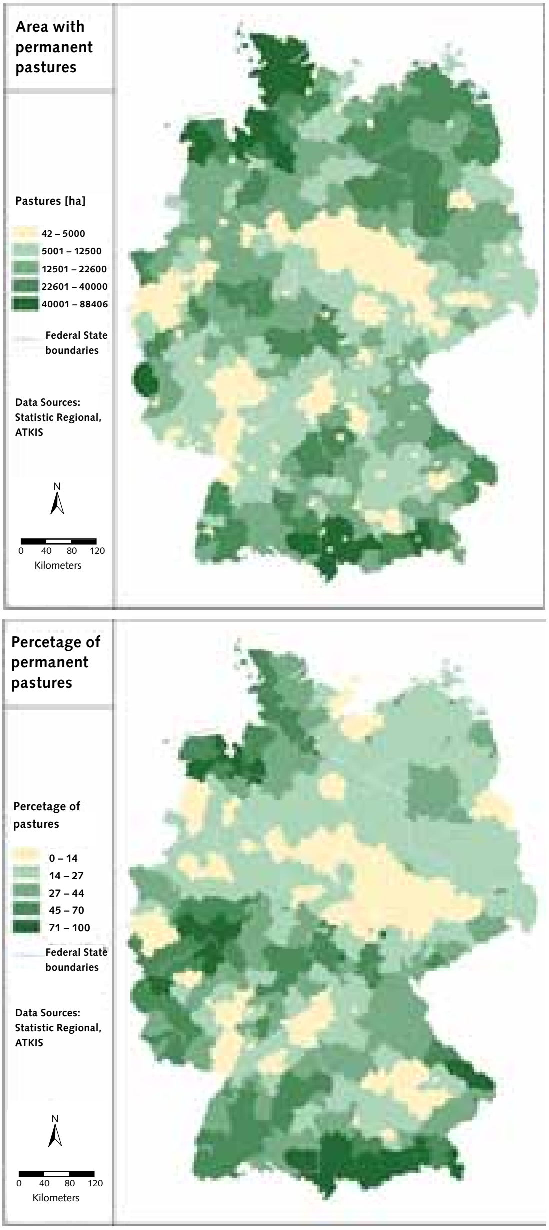
Technical note: The variable has been transformed to a relative variable. The proportion of permanent pastures/grasslands of the total agricultural area was calculated in order to compare the results across all German districts and district-independent cities. Therefore, the variable was divided by the total area used for agricultural purposes. Missing values have been interpolated by assigning the average value of the neighbouring districts.

Relevance: The indicator can be considered as technically valid. The data set is updated every two years. The calculation of a percentage guarantees the comparability of data. The only constraint is that the land use data cannot be restricted to potential floodplains in districts due to missing information on inundation areas of the rivers.

Validity: The indicator can be considered as technically valid. The data set is updated every two years. The calculation of a percentage guarantees the comparability of data. The only constraint is that the land use data cannot be restricted to potential floodplains in districts due to missing information on inundation areas of the rivers.

Visualization/Interpretation: In figure 6.15 the distribution of grasslands across the districts is visualized. A large number of pastures can be found in the alpine uplands in the south of Germany as well as in the northern parts of Germany especially in the coastal areas. In central Germany, 'Rhine Hessen', and parts of west Germany there are few pastures or permanent grasslands. The proportion of pastures of total arable lands in a district shows similar results. By contrast, in regions where poor soils or relief do not allow intensive agriculture, for example in the alpine uplands, in the low mountain range, and the coastal marshes/geests, a high percentage of pastures and grasslands exist. In the regions with fertile soils and easy access to land the percentage is usually very low. Typical examples are the 'Gäuboden' region in Bavaria, the 'Börden' region in Saxony, and Saxony-Anhalt where loess was deposited during the Quaternary Period.

Figure 6.15: Area of pasture and grassland in a district and proportion of pasture and grassland per district



Source: Author

Sector: Forest, Agriculture	**Vulnerability component:** Capacities	**Sub-component:** Coping capacities
Indicator: GDP per capita of federal state	**Measurement unit:** Euro	**Spatial and temporal scope:** Federal state, once a year

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be put out on state, provincial, and district level. The variable is an annual average.
Data type: Excel file

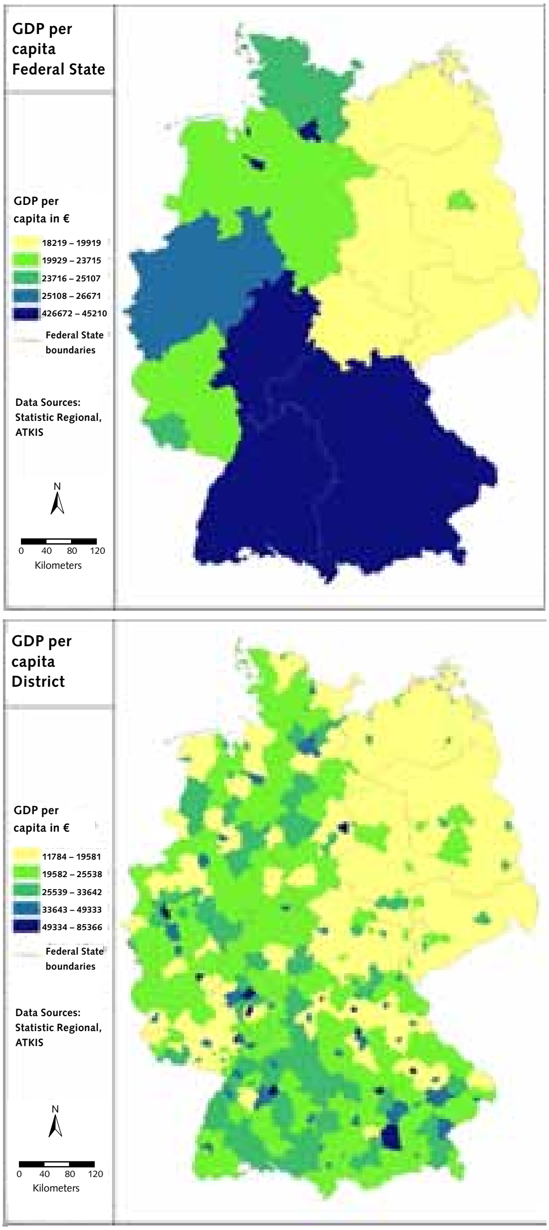
Technical note: The original data set GDP of federal states has been transformed into a relative variable. GDP per capita has been calculated in order to compare the results across all German districts and district-independent cities. Thus, GDP has been divided by the total population of a federal state. The data have been disaggregated to district level by assigning equal values to each district or district-independent city.

Relevance: As an aggregate measure of total economic production for a country, GDP represents the market value of all goods and services produced by the economy during the period measured, including personal consumption, government purchases, private inventories, paid-in construction costs, and the foreign trade balance. Growth in the production of goods and services is a basic determinant of how the economy is faring. As a single composite indicator of economic growth, it is a very powerful summary indicator of the economic state of development in its many aspects. Since financial support has been mentioned as the most important criteria in the process of coping with flooding and its consequences, economic stability and strength is regarded as an essential aspect to be considered. This means that a high GDP per capita of a federal state indicates a strong potential to provide sufficient and sustainable monetary aid.

Validity: GDP per capita is often criticized as an indicator for economic welfare because it ignores social and environmental costs, ignores the natural unequal distribution of consumption and income across the population, excludes non-market activities, and measures expenditures that do not contribute to economic welfare. However, it is still the most popular economic indicator. There are also some technical constraints with regard to the indicator's validity. As the GDP per capita of FS has to be disaggregated to district level, a substantial loss of information has to be accepted. However, the capturing of cross-scale influences and regional trends is still a major task which is accomplished by this indicator.

Visualization/Interpretation: The GDP per capita of federal states offers a quite differentiated picture of Germany (see Figure 6.16). The 'new' federal states in east Germany exhibit the lowest values in Germany with a GDP smaller than €20,000 per person. Only Berlin shows a higher GDP per capita, although it is still within at a low rank. The highest rates of GDP per capita are in Bavaria, Baden-Württemberg, and the cities of Munich, Hamburg and Bremen. The other federal states show values between €20,000 and €27,000 and thus lie in the mid range. The sharp division between east and west Germany can be traced back to the reunification of Germany (see Chapter 2) which caused strong economic changes in the 'new' federal states.

Figure 6.16: GDP per capita of F.S. and GDP per capita of German districts and district-independent cities



Source: Author

Sector: Forest	**Vulnerability component:** Capacities	**Sub-component:** Coping capacities
Indicator: Income of private households	**Measurement unit:** Euro	**Spatial and temporal scope:** District, once a year

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be produced on state, provincial, and district level. The variable is an annual average.
Data type: Excel file

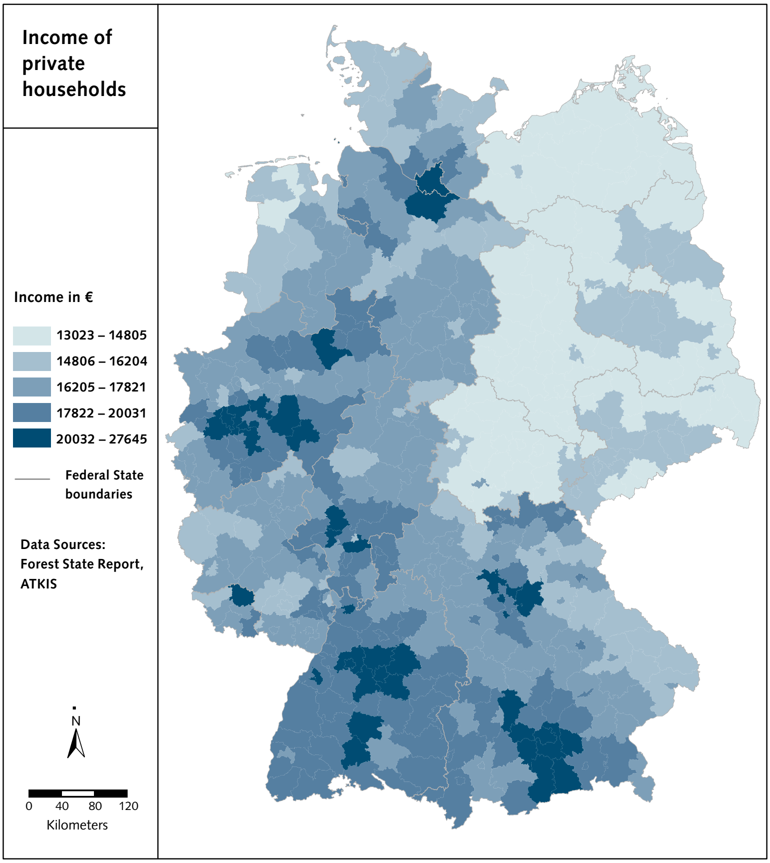
Technical note: As personal income already refers to the statistical mean income in a district, no further calculations have to be conducted.

Relevance: Whereas GDP refers to the region's potential economic welfare and the potential availability of financial resources, this indicator addresses the financial capacities of the population by capturing the mean annual income of private households. The indicator seeks to assess the financial capacities of households in a district. Financial resources are crucial for coping with the consequences of flooding. As a cross-level analysis is conducted, different levels and actors have to be considered.

Validity: The indicator is technically valid although it does not consider local inequalities. From an analytical perspective it has to be acknowledged that a correlation to GDP per capita of district might exist. However, the indicator is necessary to capture the cross-level processes and influences on the financial capacity of the entire district.

Visualization/Interpretation: Figure 6.17 maps the distribution of the mean annual income of households in districts and district-independent cities. An analysis shows that especially in the catchment area of large cities with a strong economic capacity and attractive landscape, the annual income is very high. Examples are Munich and the districts to the south in Bavaria as well as the districts in the 'Bergische Land' in North Rhine Westphalia. The regions around Stuttgart and Nürnberg are also economic hot spots. As many people prefer living in peaceful rural areas instead of hectic cities they move to the areas surrounding cities. East Germany again exhibits the lowest income classes in Germany with values that range between €13,000 and €15,000. A slightly higher income rate is recorded in Saxony and Brandenburg.

Figure 6.17: Mean annual income of households in districts



Source: Author

Sector: Agriculture	**Vulnerability component:** Capacities	**Sub-component:** Coping capacities
Indicator: % of farmers with sideline business	**Measurement unit:** %	**Spatial and temporal scope:** District, every three years

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. However, not all data is updated annually. Information about farmers with side jobs is updated every three years. The present data set is from 2003. The data set shows the number of farms and the size of farms in [ha] that operate as a sideline business.
Data type: Excel file

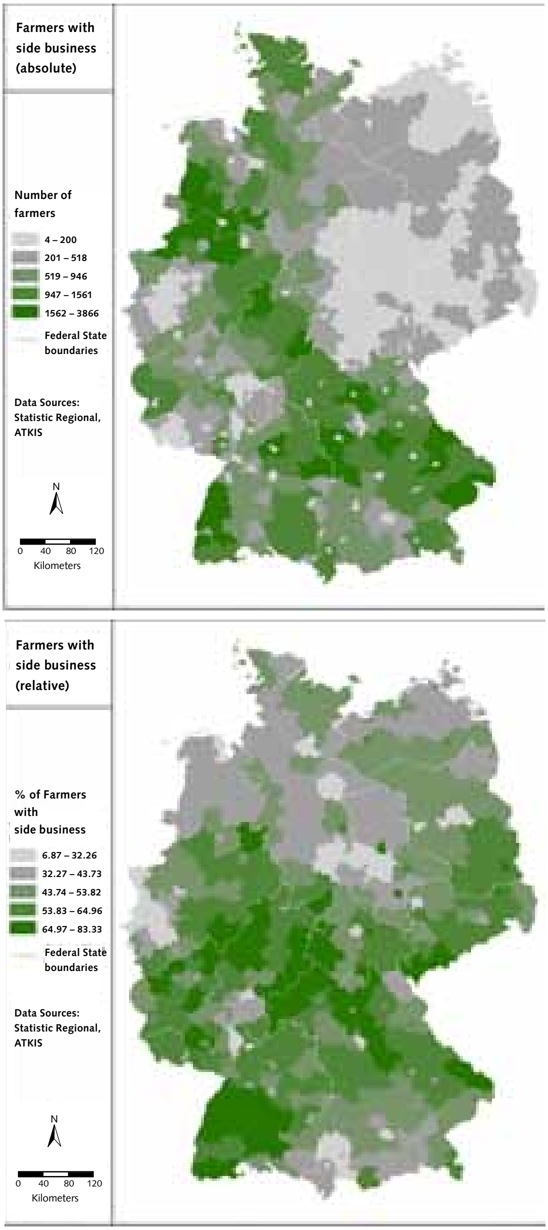
Technical note: A relative variable has been created by calculating the percentage of farms operating as a sideline business. Therefore, the number of farms has been divided by the total number of farms in a district. Missing values have been interpolated by assigning the average value of the neighbouring districts.

Relevance: The dependency on agricultural goods and services make farmers vulnerable to the loss of crops and other damage caused by flooding. However, the availability of additional income sources reduces the dependency and thus the vulnerability to the consequences of flooding. This was reported by IP6 and IP12, who obtained a good insight into the suffering of farmers during and after the flood event in 2002. Therefore, this indicator is used to reflect financial capacities.

Validity: The indicator is technically valid. The only constraint is that there is no information about the type of sideline business. Only a business that is not directly affected by the consequences of flooding can provide a stable financial backup.

Visualization/Interpretation: Figure 6.18 reveals that the total number of farmers with a sideline job is lower in east Germany than in most parts of west Germany. Only the 'Ruhr Area' region is characterized by an equally low number. However, the proportion of farmers having a side business in Germany shows another picture. Only a few districts in south, west, and central Germany do not exceed the percentage of 33 %. In districts in central Germany and in south-western Baden-Württemberg the majority of farmers have additional income (50-83 %).

Figure 6.18: Number of farmers with a side business and percentage of farmers with a side business



Source: Author

Sector: Forest	**Vulnerability component:** Capacities	**Sub-component:** Adaptive capacities
Indicator: Reforestation rate	**Measurement unit:** %	**Spatial and temporal scope:** District, new forest data every four years

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. Land use data is available for the years 1996, 2000, 2004. The data sets from 2000 and 2004 are used to determine the increase of forested area per district.
Data type: Excel file

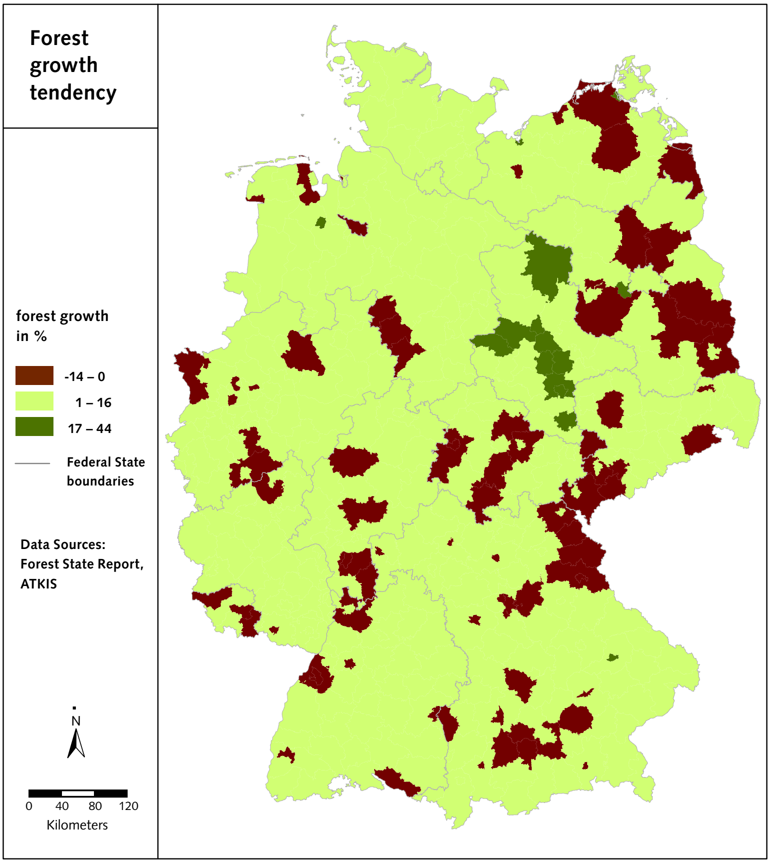
Technical note: The forest growth rate of each district is calculated by comparing the forested area in the year 2000 and 2004. A percentage is calculated showing the increase or decrease of forested area in %. Negative values indicate the decline; positive values the increase of forested area in a district.

Relevance: This indicator shows the regional trend of forest growth in a district. The indicator aims at assessing the extent to which a region has acknowledged the role of forest ecosystems for flood protection. Moreover, it reflects an overall attitude towards reforestation which is understood as a measure of adaptive land management.

Validity: The indicator is sufficiently valid. However, it is only a proxy for assessing the adaptive capacity in a district. The increase of a forested area can only be considered as positive with regard to floods when flood tolerant species are planted. As this information is unfortunately not available, the forest growth rate is accepted in the indicator set. IP18 confirmed that today forests are usually reforested with potential natural tree species. Therefore, the indicator has been approved by experts.

Visualization/Interpretation: In several districts throughout Germany a decrease in forested area has been mapped (see Figure 6.19). The decrease is particularly apparent in Brandenburg as well as in Thuringia. However, all federal states except Schleswig-Holstein exhibit a number of districts with a negative balance. The majority of districts show a tendency of forest growth. The growth ranges between 1 and 16 %. In Saxony-Anhalt many districts even show an increase of forested area above 17 %. Thus, it is the only federal state showing a strong positive trend. Additionally, some district-independent cities (Oldenburg, Straubing, and Potsdam) show a significant increase of forested area. The trend of an overall increase of forests in Germany reflects the environmental consciousness that has arisen in Germany regarding the significance of forest ecosystem functions, and cultural and provisioning services.

Figure 6.19: Forest growth tendency in German districts



Source: *Author*

Sector: Forest, Agriculture	**Vulnerability component:** Capacities	**Sub-component:** Adaptive capacities
Indicator: % protected areas	**Measurement unit:** %	**Spatial and temporal scope:** Protected areas: Polygon data, continuous updates Land use data: Scale 1:100,000, update every few years.

Data source:
Protected Areas, Federal Agency for Nature Conservation 2007,
CORINE Land Cover; Federal Environmental Agency, DLR-DFD 2004.

Data description: Several types of protected areas are designated in Germany. The different types are defined in Germany's Federal Nature Conservation Act (BNatSchG). They can be classified by size, protection purpose and conservation objective, and by the resulting restrictions on land use. The main types are nature conservation areas, national parks, biosphere reserves, landscape protection areas, and nature parks. Two or more protected areas of different types can overlap or even cover the same area of land. Additional areas have been gained by the NATURA 2000 network comprising sites designated under the Habitats Directive and the Birds Directive. It is the task of the federal states to designate and administer protected areas. Data is updated continuously by the Federal Agency for Nature Conservation. From the CORINE data set, land use data has been used for further calculations. Forested areas and all types of agricultural use were extracted from the data set.
Data type: Shape files

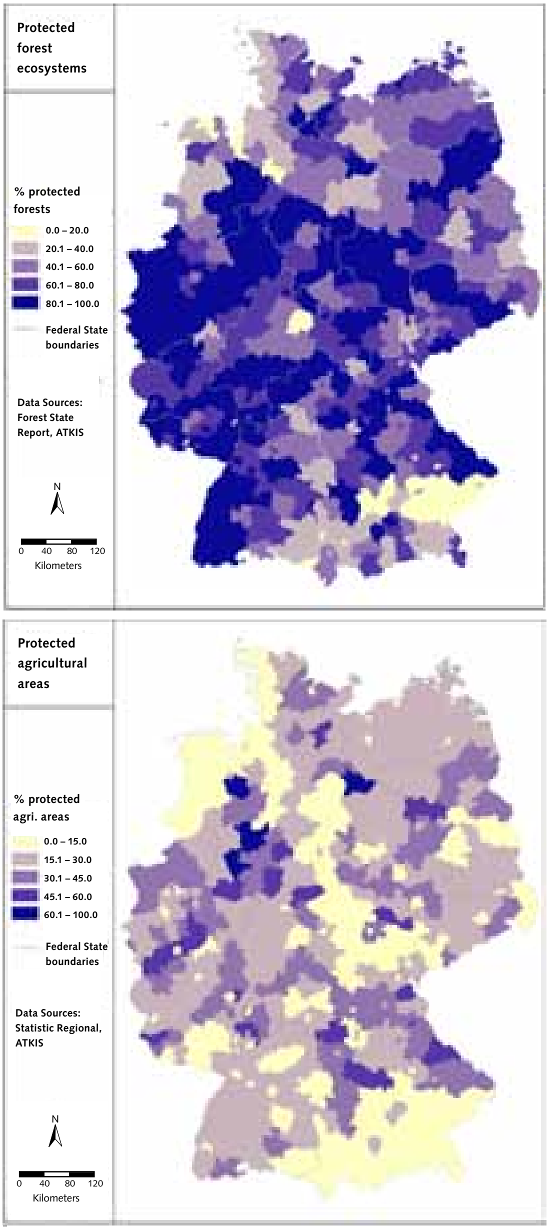
Technical note: The percentage of protected forested or agricultural area in each district has been calculated. Therefore, all types of protected areas were intersected to avoid overlaps. Subsequently, the remaining area was calculated. Then the respective land use data and protected areas were intersected. Finally, the percentage of protected area was calculated by dividing protected areas by the total forested area/agricultural area in a district.

Relevance: The existence of protected areas in Germany indicates where land is cultivated and operated sustainably through forestry and agriculture, using conservative measures. In protected areas potential natural vegetation is usually re-colonized and land management is extensive. After the Elbe flood in 2002, policymakers acknowledged the necessity of creating additional protected areas in river floodplains in order to better control human actions in an area and to favour flood-adapted management in agricultural and forested areas. By reducing human interference and enhancing ecosystem functions, it is intended that adverse flood impacts and consequences be diminished.

Validity: This indicator is sufficiently valid. However, it does not differentiate between different statuses of protected areas which regulate the degree of influence that humans are allowed to have in each area. The number of protected areas changes continuously in Germany. Data has to be updated on a regular basis. It should be stressed that the indicator is a proxy indicating the implementation of sustainable management practices in an area.

Visualization/Interpretation: A large proportion of the forest ecosystems in Germany has gained protection status. In central and western parts of Germany, 60-100 % of forests in a district lie in protected areas. Only in the south-east and north-west do numerous districts exhibit very low protected forests with percentages between 0 and 20 %. The districts close to the Alps and the North Sea in particular show a low percentage of protected forest ecosystems (20 and 40 %). Districts in North Saxony-Anhalt as well as parts of Mecklenburg-Vorpommern and Brandenburg lie in the mid range with percentages between 40 and 60 %. Numerous agricultural areas lie in protected areas (see Figure 6.20). However, the picture differs significantly from the one in the forest map. The maximum percentage of protected arable lands in a district accounts only for 74 %. Moreover, only four districts in north Germany exhibit a high rate of arable lands with protection status. The percentage in the districts usually ranges between 15 and 30 %. Especially in Bavaria, Lower Saxony and Thuringia a large number of districts have a very low protection ratio below 15 %. Most of these districts lie in high potential agricultural areas where the natural conditions guarantee a high yield. The overall low proportion of arable lands with protection status is not surprising, since agricultural ecosystems are intensively shaped and managed by human beings with the purpose of achieving high yields.

Figure 6.20: Percentage of protected forest ecosystems and protected agricultural areas in a district



Source: Author

Sector: Agriculture	**Vulnerability component:** Capacities	**Sub-component:** Adaptive capacities
Indicator: % organic farms	**Measurement unit:** %	**Spatial and temporal scope:** District, every two years

Data source:
Statistic Regional, Federal Statistical Office 2006

Data description: 'Statistic Regional' is a database created once a year by all State Statistical Offices in a joint effort. Economic, social, environmental, and demographic data are published in the database and can be displayed at state, provincial, and district level. However, not all data is updated annually. The last collection of information on organic farming data took place in 2003.
Data type: Excel file

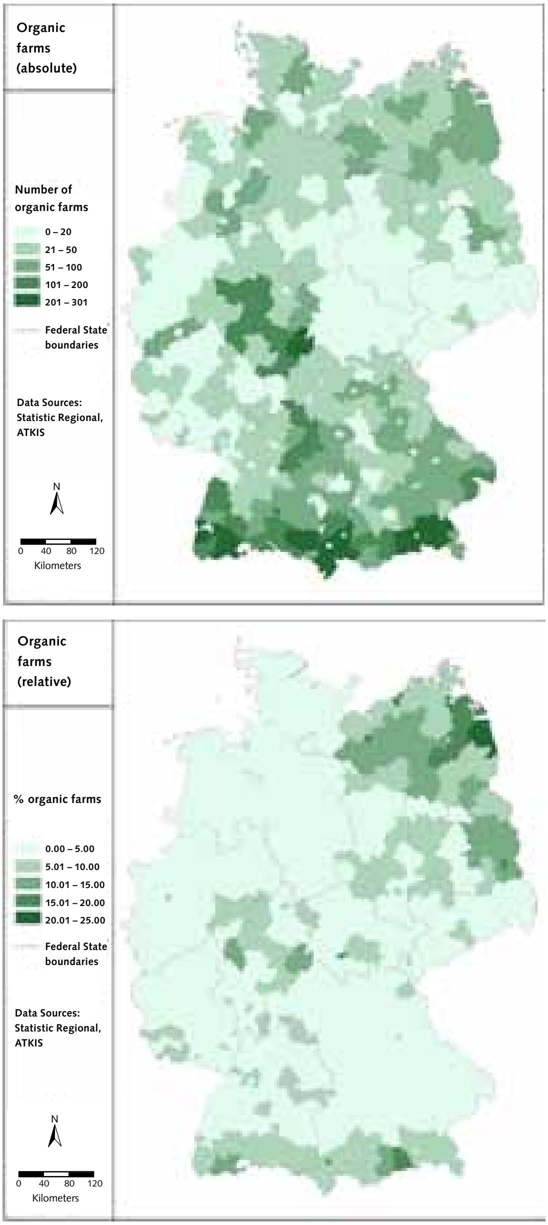
Technical note: The original data set 'number of organic farms in a district' has been transformed to a relative variable. The proportion of organic farms has been calculated in order to compare the results across all German districts and district-independent cities. Thus, the number of organic farms has been divided by the total number of farms in a district. Missing values have been interpolated by assigning the average value of the neighbouring districts.

Relevance: It has been proved by several scholars that the conservative land management practised by organic farms contributes to enhanced flood prevention in agricultural areas. The reason is that the infiltration capacity is increased due to the applied management practices (e.g. mulch coverage). On the other hand, soil compaction and soil sealing are clearly reduced by these practices. The change from conventional to conservative cropping in floodplains is therefore explicitly recommended by Wilcke et al. (2002), Schönleber (2006) and Schmidt et al. (2006) as an adaptation strategy.

Validity: Technically, the indicator is valid. Analytically, it must be mentioned that the change to organic farming is still not widely recognized amongst farmers and farm associations as an adaptive strategy for flood prevention and protection. Thus, the distribution of organic farms across districts is arbitrary and not explicitly related to flood protection. Nevertheless, the indicator is a valuable measure to compare potential capacities across regions and was approved by the experts as sufficiently valid.

Visualization/Interpretation: Figure 6.21 maps the number and percentage of organic farms in a district. The largest number of organic farms emerges in the alpine uplands and in Hessen. Between 200 and 300 organic farms are counted here. By contrast, the lowest numbers can be found in the federal states of Saxony, Thuringia, and Saxony-Anhalt where the districts rarely have more than 20 organic farms. In North Rhine Westphalia and Rhineland-Palatinate organic farm management is not common, as the very low numbers reflect. The percentages show that beside the districts in south Germany and Hessen there is also a high proportion of farms that are managed organically in north-east Germany. The highest percentage is in the district 'Uecker-Randow' in Mecklenburg-Vorpommern with 24 %. Other districts with a high percentage range between 15 and 20 %. However, altogether, three quarters of Germany's districts exhibit zero organic farms or a very low percentage (0-5 %). The analysis shows that organic farm management only concentrates on certain regions and is not broadly applied throughout Germany.

Figure 6.21: Number of organic farms and percentage of organic farms in a district



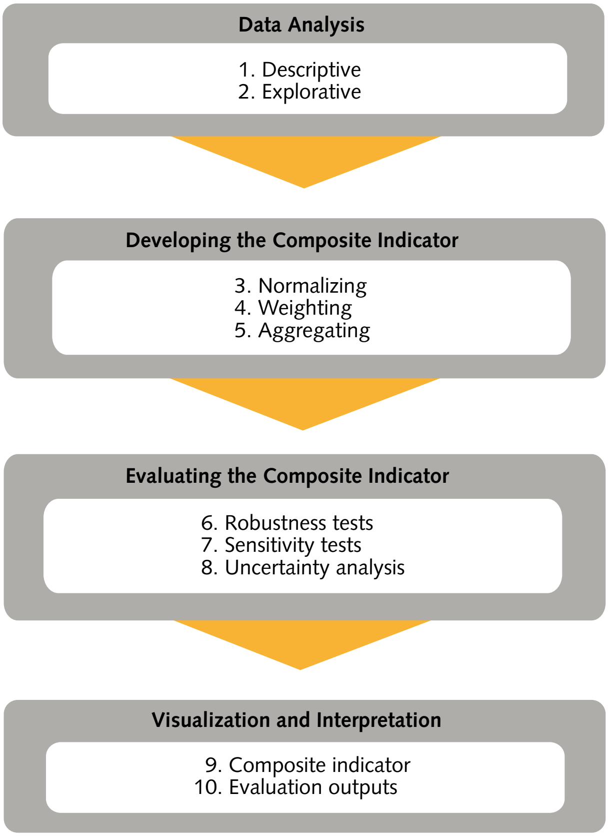
Source: Author

7. Development and evaluation of a composite indicator

7.1 Overview of the methodological approach

Development and evaluation of the composite vulnerability indicator requires a sequence of different work steps, which are presented in figure 7.1. Following the developed methodology, this chapter provides first an overview of the selected methods for composing and evaluating the vulnerability composite indicator.

Figure 7.1: Structure for development and evaluation of the composite vulnerability indicator



Source: Author

Subsequently, the results of the vulnerability calculations are presented by mapping them across districts in Germany. Moreover, the findings from the evaluation process are outlined. The chapter closes with a brief description of the methods and results of the development of a disaster risk index. This is demonstrated by considering several districts along the rivers Elbe and Rhine.

7.2 Methods for developing and evaluating the composite indicator

The first three main components from Figure 7.1 are presented in this section. Thus, data analysis, techniques for composing the vulnerability indicator, and evaluation methods are described.

7.2.1 Data analysis

A descriptive and explorative data analysis was carried out to assess the suitability of the data set and to provide an understanding of the implications of the methodological choices, e.g. weighting and aggregation, during the construction phase of the composite indicator. Individual indicators can have high correlations which can lead to indices which overwhelm, confuse, and mislead decision makers and the general public. Thus, the underlying nature of the data needs to be carefully analysed before the composite indicator is constructed. First of all, a descriptive analysis of the indicators is performed. Thereafter, a bivariate correlation analysis is carried out with a common statistical program.

Descriptive analysis:

A descriptive analysis is the first step to understanding the existing data set. Therefore, all indicators were characterized by their minimum, maximum, range, mean, and standard deviation. Whereas in the agricultural data set all districts (439 cases) were analysed and processed, in the forest data set six cases were excluded from further calculations. Districts with a forest rate lower than 2 % were ignored in the approach due to the high possibility of spatial inaccuracies that might have taken place during the intersection of forest and administrative data in GIS. Thus only 433 districts were considered in the subsequent calculations.

Table 7.1 shows the different characteristics of the indicators in the agricultural data set. The four ordinal variables ggk (water quality index), occ (organic carbon content), texture, and erodibility range between 1 and 5 and exhibit a low standard deviation. The other variables are metric and have very different data ranges. Due to the distinct units and formats the indicators have to be normalized to make them comparable with each other. The descriptive statistics of all forest indicators was calculated considering 433 districts (see Table 7.2).

The result reflects the variety of different data types. Two ordinal variables (ggk, forest size) are included in the data set. The other indicators are metric and have different data units and formats. Thus, diverse data ranges and standard deviations exist in the data set. The indicator ‘forest growth’ can also exhibit negative values. Therefore, the different indicators had to be normalized.

Table 7.1: Descriptive statistics for the agricultural data set

DESCRIPTIVE STATISTICS FOR THE AGRICULTURAL DATA SET

Indicators	Number of cases	Range	minimum	maximum	Mean	Standard deviation
farmland (%)	439	78.03	4.92	82.95	47.90	4.92
employees (%)	439	12.10	0.16	12.26	3.24	0.16
GVA (%)	439	7.79	0.04	7.82	1.66	0.04
unemployment (%)	439	11.48	2.16	13.64	6.09	2.16
erodibility	439	3	2	5	3.75	2
ggk	439	6	1	7	3.70	1
contamination	439	9.66	0.11	9.77	1.04	0.11
occ	439	2	1	3	1.73	1
texture	439	4	1	5	2.87	1
pastures (%)	439	99.26	0.55	99.89	31.47	0.55
gdpcapita_fs (€)	439	26991	18219	45210	25935.03	18219
gdpcapita_ct (€)	439	73582	11784	85366	24884.97	11784
side business (%)	439	76.46	6.87	83.33	50.15	6.87
org. farms (%)	439	24.37	0.00	24.37	3.68	0.00
prot. areas (%)	439	73.64	0.21	73.85	20.94	0.21

N = number of cases, min = minimum, max = maximum, SD = standard deviation

Source: Author

Correlation analysis:

A correlation analysis indicates the strength and direction of a linear relationship between two variables. The Pearson correlation coefficient has been calculated with the absolute metric variables, whereas the relationships between and with ordinal variables have been determined by means of the Spearman correlation coefficient (Backhaus et al. 2006). All coefficients above the threshold of r = 0.65 indicate a high correlation and are therefore carefully evaluated.

- The correlation analysis of the indicator set for the agricultural sector delivers the following results:

- The variables *employees* and *farmland* are significantly correlated (r=0.69). As both indicators belong to the exposure component, the removal of one variable can be considered. However, the two indicators fulfil also an analytical purpose that must not be ignored. The first represents exposure of the social sub-system, whereas farmland stands for the ecological sub-system.

Table 7.2: Descriptive statistics for the forest data set

DESCRIPTIVE STATISTICS FOR THE FOREST DATA SET						
Indicators	Number of cases	Range	minimum	maximum	Mean	Standard deviation
forest area (%)	433	62.82	2.17	64.99	27.9869	14.96
employees (%)	433	12.10	0.16	12.26	3.2741	2.39
GVA (%)	433	7.79	0.04	7.82	1.6767	1.48
unemployment (%)	433	11.48	2.16	13.64	6.0864	2.68
forest damage (%)	433	39	9	48	29.36	9.74
ggk	433	6	1	7	3.70	0.72
size	433	4	1	5	4.04	1.36
forest type (%)	433	100.00	0.00	100.00	56.2092	31.42
fragmentation	433	3.63	0.00	3.63	.7000	0.42
gdpcapita_ct (€)	433	73582	11784	85366	24806.34	10033.24
gdpcapita_fs (€)	433	26991	18219	45210	25932.93	5195.96
income (€)	433	24453	13023	37476	17696.85	3650.31
forest growth (%)	433	57.28	-43.55	13.73	-2.0240	5.68
prot. areas (%)	433	73.64	0.21	73.85	21.0242	13.34

Source: Author

- *Gross value added* (GVA) is very strongly correlated with the two variables *farmland* and *employees*. The coefficient is r = 0.82 in the first and r = 0.92 in the second case. As employees and GVA both represent the social system's exposure, one indicator is redundant and can be removed from the indicator set to avoid doubling effects.
- The variables *pasture* and *farmland* are also correlated, which is indicated by the correlation coefficient of r = 0.69. However, both variables are grouped into different vulnerability components and are supposed to represent different issues. *Farmland* indicates the potential exposure of arable lands, whereas the indicator *pastures* aims at reflecting the degree to which arable lands are resilient to flooding conditions. Therefore, the correlation between both variables can be ignored.
- *Unemployment* and *GDP* of a district also show a fairly strong correlation of 0.78. The same argument as above can be used here to justify the use of both indicators. Hence, they belong to different vulnerability components and indicate distinct issues, and therefore can remain in the data set.

- *Sideline business* exhibits a correlation coefficient of r = 0.74 with the variable *employees*. This relationship can be ignored in this approach as both variables have been grouped into different vulnerability components. Farmers with a sideline business indicate the potential of having additional financial resources, while employees represents exposure of the social sub-system.
- The variables *protected areas* and *farmland* in a district are correlated as well (r = 0.68). Since both indicators represent different vulnerability components the relationship will not be considered.

The results of the correlation analysis of the forest sector indicators can be summarized as follows:

- *Gross value added* and *employees* are very strongly correlated with r = 0.92. As both indicators aim at representing the same issue, one should be removed from the data set to avoid doubling effects.
- *Forest fragmentation* correlates considerably with the indicators *employees* (r = 0.56) and *GVA* (r = 0.68). However, since fragmentation is grouped into another category with another aim, the correlation can be ignored.
- *Unemployment* and *GDP* of a district show a strong correlation with r = 0.78. (see argumentation above)

Conclusion:

The correlation analysis has proved that various correlations with r > 0.65 exist. However, in most cases the correlation can be ignored as the objective and represented issue differs among the correlated indicators. Only GVA and employees of forest/agricultural sector exhibit a very strong correlation, and additionally they are in the same category. Thus, GVA has been removed from the data set of both sectors and was not used in any further calculation.

7.2.2 Transformation and normalization

Prior to the normalization of data the variables were tested on their skewness and normality of distribution. In many cases the observations show substantial skewness of the variables. However, the decision was made not to transform any variables as this leads to a significant change of the data structure, aggravates later interpretation, and suppresses the existence of extreme values.

The indicators are expressed in a variety of statistical units, ranges, or scales. Before starting with the actual weighting and aggregation procedure, they have to be adjusted and transformed to a uniform dimension to avoid problems in mixing measurement units. The selection of a suitable normalization method to apply to the problem at hand is not trivial and requires special care. The normalization method should take into account the data properties and the objectives of the composite indicator. The selection of the normalization method depends on (1) whether hard or soft data are available, (2) whether exceptional behaviour of, for example, outliers needs to be rewarded/penalized, (3) whether information on absolute levels matters, (4) whether benchmarking against a reference country is requested, and (5) whether the variance in the indicators needs to be accounted for (Nardo et al. 2005).

In this study the standardization (or z-score) method has been selected as the normalization technique. The method calculates the average value and the standard deviation for each indicator. The normalized indicator is then calculated as the ratio of the difference between the raw indicator value and the average divided by the standard deviation.

$$z_i = \frac{x_i - \bar{x}}{s_x} \qquad (3)$$

$\bar{x}$ = average

s_x = standard deviation

z_i = transformed variable

This type of normalization is the most commonly used because it converts all indicators to a common scale with an average of zero and standard deviation of one (Nardo et al. 2005). The average of zero means that it avoids introducing aggregation distortions stemming from differences in indicator means. The scaling factor is the standard deviation of the indicator.

In other approaches, the scaling factor is the range of the distribution, rather than the standard deviation, which means that extreme values can have a large effect on the composite indicator. This might be desirable if the intention is to reward exceptional behaviour, that is, if an extremely good result on a few indicators is thought to be better than many average scores. As it is not desired to reward outliers, the z-score transformation is preferred. However, it has to be taken into account that the normalized indicators do not have the same data range. Moreover, negative and positive values are the result of the normalization procedure (see Table 7.3). This method has, for instance, been used for the Environmental Sustainability Index (ESI) (Esty et al. 2005).

7.2.3 Weighting

Central to the construction of a composite indicator is the need to combine the indicators in a meaningful way. This implies that a decision must be made on a specific weighting model. A number of different weighting techniques exist. Some are derived from statistical models, such as factor analysis or data envelopment analysis, some come from participatory methods such as budget allocation and analytic hierarchy processes (AHP), and others are a combination of statistical method and expert judgment, such as correlation analysis. While some types of analysis might use weights based only on statistical methods, others might reward or neglect components depending on expert opinion to better reflect the policy priorities or theoretical factors. Weighting models need to be made explicit and transparent, since weights usually have an important impact on the value of the composite indicator and on the resulting ranking.

Table 7.3: Descriptive statistics of the normalized data set – example forest sector indicators

DESCRIPTIVE STATISTICS OF THE NORMALIZED DATA SET – EXAMPLE FOREST SECTOR INDICATORS				
Variable	Minimum	Maximum	Mean	Standard deviation
Zscore (forestrate)	-1.7248	2.4722	0	1
Zscore (emplrate)	-1.2987	3.7475	0	1
Zscore (unemplrate)	-1.4635	2.8154	0	1
Zscore (damagerate)	-2.0898	1.9141	0	1
Zscore (ggk)	-3.7213	4.5348	0	1
Zscore (size)	-0.7036	2.2187	0	1
Zscore(foresttype)	-1.7884	1.3933	0	1
Zscore (fragm)	-6.8387	1.6321	0	1
Zscore (gdpcapita_ct)	-1.2979	6.0359	0	1
Zscore (gdpcapita_fs)	-1.4846	3.7100	0	1
Zscore (income)	-1.2804	5.4185	0	1
Zscore (growthrate)	-2.7696	7.3005	0	1
Zscore (protareas)	-1.5598	3.9588	0	1

Source: Author

This study favoured the use of statistical methods to derive weights for the different indicators. The reason is that expert judgement always implies high subjectivity. Moreover, the experts admitted in the interviews that the concept of vulnerability was not familiar to them. Thus, they had difficulties in deciding on the significance and relevance of different components and indicators. The fact that a regional approach is conducted additionally aggravates this problem. The majority of experts pointed out that a large-scale approach makes weighting difficult, since political priorities and relevance of certain components differ from region to region. Therefore, the transferability of weights cannot be assured in a Germany-wide approach.

For this reason, in this research weights have been assigned to single indicators with regard to remaining correlations, data quality, and analytical accuracy. Table 7.4 presents the weights that were finally assigned to the indicators. The two indicators '% of farmland' and '% of employees' in the agricultural data set received lower weights due to a remaining correlation between both indicators. Both represent the vulnerability component of exposure, even though they do so in two different sub-components. Therefore, the indicators are kept but are adjusted by weights. A weight is also assigned to the indicator '% of employees' in the forest data set, since the analytical inaccuracy has to be considered as well. The indicator informs only about employees in the forest and agricultural sectors and not about employees in each individual sector. This has to be penalized by a lower weight. Data quality of indicators is a further major constraint that has to be taken into account in the vulnerability calculation. A lack of data quality arises from the up- and downscaling of data to district level or from uncertainties in the original data. Forest data, for instance, are derived from the CORINE data set which was collected in the year 2000 (UBA 2004). Since 'forest area' and 'type' are not static but have probably changed in the meantime, data quality is certainly reduced. Moreover, soil data, such as 'texture' and 'erodibility' had to be aggregated significantly to district level. Due to the natural variability of soil characteristics, soil information has definitely been lost. Beside weights, table 7.4 also provides the reasons for the assignments of weights.

Table 7.4.1: Indicators and weights (forest sector)

FOREST SECTOR		
Indicators	Weights	Reason
% forested area	1	-
% employees in agro-forestry sector	0.5	Analytical inaccuracies
Unemployment rate of district	1	-
% damaged forest	0.5	Disaggregation
Water quality index	0.5	Aggregation
Forest size	0.5	Data inaccuracies
Forest fragmentation	0.5	Data inaccuracies
Forest type	0.5	Data inaccuracies
GDP per capita of FS	0.5	Disaggregation
GDP per capita of district	1	-
Income of private households	1	-
Reforestation rate	1	-
% protected areas	1	-

Source: Author

Table 7.4.1: Indicators and weights (agricultural sector)

AGRICULTURAL SECTOR		
Indicators	Weights	Reason
% farmland	0.5	Correlation
% employees in agro-forestry sector	0.5	Data inaccuracies/correlation
Unemployment rate of district	1	-
Soil erosion potential	0.5	Aggregation
Water quality index	0.5	Aggregation
Contamination potential	1	-
Water storage capacity – Texture	0.5	Aggregation
Filter and buffer capacity - OCC	0.5	Aggregation
% permanent grasslands/pastures	1	-
GDP per capita of FS	0.5	Disaggregation
GDP per capita of district	1	-
% of farmers with additional income	1	-
% organic farms	1	-
% protected areas	1	-

Source: Author

7.2.4 Aggregation

Literature on composite indicators offers several examples of aggregation techniques (Nardo et al. 2005). The most commonly used are additive techniques which range from summing up of ranks to aggregating weighted sums of the single indicators. Less widespread aggregation methods such as geometric aggregation techniques or nonlinear aggregation (e.g. multi-criteria or the cluster analysis) are also applied (Broyer and Savry 2002; Munda 2004).

The most common linear aggregation is the summation of weighted and normalized individual indicators. This technique is applied in this research (see Equation 4).

$$CI_d \qquad \sum_{q=1}^{Q} w_d \; I_{qd} \tag{4}$$

CI = composite indicator

d = district

q = sub-indicator, Q *= number of indicators*

w = weight

I = normalized indicator

Although widely used, this aggregation method imposes restrictions on the nature of sub-indicators. In particular, obtaining a meaningful composite indicator depends on the quality of the underlying data and the unit of measurement of these sub-indices. Furthermore, additive aggregations have important implications on the interpretation of weights. An additive aggregation function exists only if these indicators are mutually and preferentially independent. This means that the function permits the assessment of the marginal contribution of each variable separately.

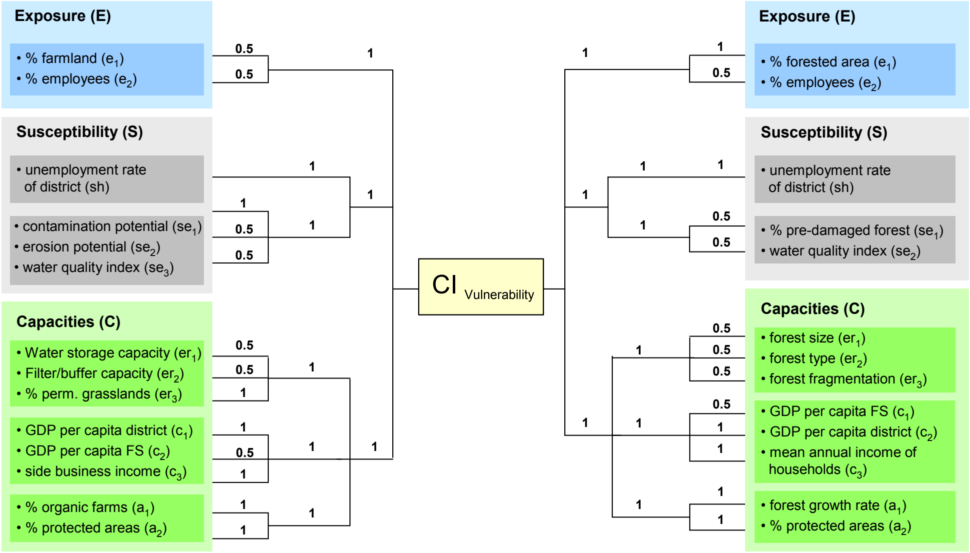
In figure 7.2 the aggregation process is depicted for both sectors of interest. Since vulnerability is composed of different components and sub-components a three-tiered aggregation model is developed. First, all indicators within a sub-component are summed up by applying the weights from Table 7.4. Subsequently, the scores of the sub-components are aggregated for each component by using equal weights within a component. Equal weights are also applied during the last step when the exposure, susceptibility and capacities indices are summed up (see Equation 5).

$$V_{ulnerability} = E_{xposure} + S_{ensitivity} + (-C_{apacities}) \tag{5}$$

To assure the comparability of indices and sub-indices during the calculation process, the sums are divided by the number of respective indicators and sub-components. For instance, the sub-component ‘coping capacities’ consists of three indicators. Thus, the formula is:

$$C_{oping}C_{apacities} = \frac{\sum_{q=1}^{Q} w_d \, I_q}{3} \tag{6}$$

Figure 7.2: Indicators and the weighting scheme for agricultural sector (left) and forest sector (right)



Source: Author

7.2.5 Evaluation

This section focuses on aspects of index robustness, sensitivity, and uncertainty. It outlines the methods applied to test the quality of the composite vulnerability indicator. Evaluating a composite indicator is one of the most important steps in a quantitative vulnerability assessment as both the development of indicators and the building of a composite indicator inherit numerous uncertainties. Subjective decisions during the development of indicators, the dependence of data and information from various external sources, scaling of data, and finally the selection of a normalization, weighting, and aggregation technique all create serious uncertainties. "Since the quality of a model depends on the soundness of its assumptions, good modelling practices require that the modeller provides an evaluation of the confidence in the model, assessing the uncertainties associated with the modelling process and the subjective choices undertaken" (Nardo et al. 2005: 81).

The following procedure has been developed to cope with uncertainties in the present approach: (1) technical robustness and mathematical design is explored in more detail by comparing the results of different normalization, weighting, and aggregation techniques. Subsequently, (2) the behaviour of the input variables and vulnerability index is analysed by means of correlation and sensitivity analyses. A sensitivity analysis is capable of assessing the degree of contribution and representation of an indicator in the final index score. These statistical findings are then (3) complemented by a Monte Carlo Analysis (MCA) which aims at assessing sensitivities and uncertainties within the vulnerability calculation model.

7.2.5.1 Robustness tests

The first step in testing the robustness of the composite indicator and the reliability of the calculation model is to compare different normalization, weighting, and aggregation procedures. The aim is to see whether different techniques produce a high variance in the composite indicator or whether the final result is stable and sound.

Normalization:

Beside the z-score standardization method, two other normalization techniques are applied to calculate the vulnerability index. The 're-scaling' method normalizes indicators to have an identical range between [0, 1]. Extreme values or outliers, however, can distort the transformed indicator. On the other hand, re-scaling widens the range of indicators lying within a small interval, increasing the effect on the composite indicator to a greater extent than the z-scores transformation does. Equation 7 was used to perform the re-scaling of the indicators. Subsequently, the rescaled values were weighted and aggregated to build the composite vulnerability indicator.

$$CI_q = \frac{x_q - \min(x_q)}{\max(x_q) - \min(x_q)} \tag{7}$$

CI = composite indicator, q = sub-indicator

The second method uses a categorical scale and assigns a certain score to each indicator. Categories can be numerical or qualitative. Often, the scores are based on the percentiles of the distribution of the indicator across units. Categorical scales exclude large amounts of information about the variance of the transformed indicators. Besides, when there is little variation within the original scores, the percentile bands force categorization on the data, irrespective of the underlying distribution. This study used five categories. This means that for each indicator, each district received a score between 1 and 5 using the equal distance method to assign the respective score. Finally, the categorized values were weighted and aggregated as described in the previous paragraphs, and again ranked in five classes.

Weighting:

Two additional weighting methods are tested to evaluate the robustness of the composite indicator. The first technique assigns equal weights to all variables. However, equal weighting does not mean 'no weights', but implicitly implies that the weights are equal. The advantage of this method is that the weights are not produced by subjective interpretation or pure mathematical method. Moreover, the method is easily understandable and reproducible. On the other hand, equal weighting disguises the absence of statistical or empirical facts. For example, correlations between indicators produce double weights. To analyse the result of the equal weighting method, equal weights have been assigned to each standardized input variable. Subsequently, the variables were aggregated to a composite indicator.

Ideally, weights should reflect the contribution of each indicator to the overall composite. Statistical models such as principal components analysis (PCA) can be used to weight and group sub-indicators. This method accounts for the highest variation in the data set, using the smallest possible number of factors that reflect the underlying statistical dimension of the data set. The main advantage of the PCA method is that weights are based on a statistical method and not on subjective opinions. However, the calculated components do not usually correspond to the components of the conceptual framework. Moreover, PCA is quite complex and not easily understandable for potential end-users. Finally, correlations between the different indicators are a prerequisite to performing a PCA. A detailed discussion on factor analysis can be found in Hair et al. (1995).

The PCA allows the construction of weights representing the information content of the underlying indicators. Various stopping rules have been developed (see Nardo et al. 2005). This study follows the variance-explained criteria and chooses factors that represent more than 60 % of the overall variance given by the underlying data. Furthermore, the Varimax Rotation is selected which is, according to Bühl (2006), the most common rotation method. Rotation is used to minimize the number of sub-indicators that have a high loading on the same factor. Subsequently, weights are constructed from the matrix of factor loadings. Nicoletti et al. (2000) point out that the square of factor loadings represents the proportion of the indicator's total variance, which is explained by the factor. The weight is calculated as follows: (Factor loading)^2/Total Variance of the rotated square loadings. The calculated weights and factors are displayed in Table 7.5 and Table 7.6. Weights are marked in dark grey. Finally, the components are weighted by using the proportion of the explained variance in the dataset and summed up.

Aggregation:

In this research, a geometric aggregation has been performed in order to test the robustness of the selected additive aggregation technique. Whereas additive methods compensate the poor performance in some indicators by sufficiently high values of other indicators, the use of a geometric aggregation is an intermediate solution. However, the measurement scale must be the same for all indicators, thus the rescale normalization method was applied before starting the aggregation process. Equation 8 is used to conduct the geometric aggregation.

$$CI_d = \sqrt{\prod_{q=1}^{Q} x_{qd}^{w}} \tag{8}$$

CI = composite indicator, d = district, q = sub-indicator, w = weight associated to sub-indicator

Nardo et al. (2005) point out that linear aggregation rewards indicators proportionally to their weights, while geometric aggregation favours those indicators or sub-components with higher scores. Thus, compensability is constant in linear aggregation, while it is smaller in geometric aggregation.

Table 7.5: Factor loadings and weights for the forest sector indicators

FACTOR LOADINGS AND WEIGHTS FOR THE FOREST SECTOR INDICATORS								
Rotated Component Matrix								
	Factor Loadings				Factor Weights			
	1	2	3	4	1	2	3	4
forest rate	.342	.783	.113	-.248	0.04	0.32	0.01	0.00
empl rate	-.028	-.016	.722	-.423	0.00	0.00	0.31	0.00
unempl rate	-.890	.012	-.086	.042	0.27	0.00	0.00	0.00
damage rate	.770	.154	-.199	.120	0.20	0.01	0.02	0.00
ggk	-.420	-.302	-.043	.049	0.06	0.05	0.00	0.00
forest size	-.035	.901	-.046	-.047	0.00	0.42	0.00	0.00
forest type	.029	-.111	-.140	.781	0.00	0.01	0.01	0.41
fragmentation	-.299	.531	.180	.488	0.03	0.15	0.02	0.00
gdpcapita_ct	.343	-.101	-.745	.168	0.04	0.01	0.33	0.00
gdpcapita_fs	.854	-.116	-.165	-.021	0.24	0.01	0.02	0.00
income	.404	-.231	-.058	.326	0.05	0.03	0.00	0.00
growthrate	-.426	-.146	-.012	.330	0.06	0.01	0.00	0.00
prot area rate	.139	.038	.666	.366	0.01	0.00	0.27	0.00
Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization.								
Expl. Var	2.981	1.935	1.667	1.486				
Expl. Tot	0.37	0.24	0.21	0.18				

Source: Author

Table 7.6: Factor loadings and weights for the agriculture sector indicators

FACTOR LOADINGS AND WEIGHTS FOR THE AGRICULTURE SECTOR INDICATORS										
Rotated Component Matrix										
	Factor Loadings					Factor Weights				
	1	2	3	4	5	1	2	3	4	5
farmlandrate	.796	.087	.112	-.248	.053	0.22	0.00	0.01	0.04	0.00
emplrate	.907	-.104	.064	.131	.083	0.28	0.01	0.00	0.01	0.01
GVArate	.907	.122	.135	.071	.032	0.28	0.01	0.01	0.00	0.00
unempl_rate	-.014	.901	.095	.066	-.132	0.00	0.38	0.01	0.00	0.01
erodibility	.115	.172	.811	-.088	.013	0.00	0.01	0.38	0.00	0.00
ggk_med	-.053	.465	.068	-.403	.036	0.00	0.10	0.00	0.10	0.00
cont_rate	-.360	-.071	-.020	-.462	.168	0.04	0.00	0.00	0.13	0.02
occtop	.008	-.030	.309	-.115	.736	0.00	0.00	0.06	0.01	0.43
texture	-.089	.050	-.769	-.307	-.025	0.00	0.00	0.34	0.06	0.00
past_rate	-.228	-.297	.017	.604	.202	0.02	0.04	0.00	0.22	0.03
gdpcapita_fs	-.216	-.863	-.044	-.043	-.055	0.02	0.35	0.00	0.00	0.00
gdpcapita_ct	-.599	-.388	.181	-.212	-.371	0.12	0.07	0.02	0.03	0.11
sidebusi_rate	-.053	-.117	-.492	.423	.443	0.00	0.01	0.14	0.11	0.15
orgfarms_r	.065	.243	.129	.680	-.178	0.00	0.03	0.01	0.28	0.02
protarea_rate	.171	-.002	-.227	-.051	.509	0.01	0.00	0.03	0.00	0.20
Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization.										
Expl. Var	2.981	2.154	1.737	1.635	1.268					
Expl. Tot	0.37	0.22	0.22	0.17	0.13					

Source: Author

7.2.5.2 Sensitivity and uncertainty analysis

A sensitivity analysis is conducted to work out how the variation in the output can be apportioned, qualitatively and quantitatively, to different sources of variation in the assumptions, and how the given composite indicator depends upon the information fed into it. Sensitivity analysis is thus closely related to uncertainty analysis which aims to quantify the overall uncertainty in the vulnerability index as a result of the uncertainties in the model input. A combination of uncertainty and sensitivity analysis facilitates the evaluation of reliability and soundness of the vulnerability composite indicator. Moreover, it improves transparency and starts a debate around the output.

Correlation analysis:

First, the sensitivity of the composite indicator and its input parameters is examined by conducting a correlation analysis. Therefore, the coefficient of determination (r^2) is calculated to determine the degree of variability between both parameters. The analysis is only carried out with metric indicators that were available at district level. For the forest sector these are the indicators: forested area, employees, forest type, GDP per capita of district, fragmentation, forest growth rate, unemployment rate, protected areas and income of households. For the agricultural sector the following indicators have been compared regarding their influence on the output: farmland, contamination rate, organic farms, employees, sideline business, protected areas, unemployment rate, pasture rate, and GDP per capita of district.

Change of indicator values:

Subsequently, the sensitivity of the vulnerability composite to any variability in the input data set is investigated. Certain indicators have been changed or omitted to explore the impact of variations on the composite indicator. Therefore, vulnerability of the forest sector is calculated an additional six times; first, excluding GDP per capita of federal states, second, omitting forest growth rate, and third excluding the water quality index. Subsequently, runs four, five, and six are calculated by using the overall mean across all districts of each named indicator instead of the original values.

For the agricultural sector, four additional simulations have been calculated. GDP per capita of the federal states and the water quality index are omitted in the first two runs. Then the mean of both variables is used to calculate vulnerability for each district.

Monte Carlo Analysis:

The effect of natural heterogeneity of vegetation and soil on the vulnerability is a major source of uncertainty when running vulnerability simulations on a subnational scale. In a regional vulnerability study it is usually necessary to upscale information and data of soils and vegetation. Therefore, the calculations imply the assumption that the attributes of each district are uniform. However, this is very unlikely due to the natural variability of soil and vegetation characteristics.

The Monte Carlo (MC) method is one of the most widely used means for uncertainty analysis, with applications ranging from risk assessments (Moore and Warren-Hicks 1998) to economic studies (Fenwick et al. 2001). These methods involve random sampling from the distribution of inputs and successive model runs until a statistically significant distribution of outputs is obtained. They can be used to solve problems with physical probabilistic structures, such as uncertainty propagation in models or solution of stochastic equations. Monte Carlo methods rely on repeated random sampling to compute new results and tend to be used when it is infeasible or impossible to compute an exact result with a determinist algorithm (Fishman 1995).

In this study the Monte Carlo analysis has been carried out by using a common statistical program. A routine was built that calculates vulnerability 2000 times per district to form a probability distribution of the vulnerability index. For each vulnerability scenario the routine selects a random value for the indicator's erodibility, OCC, and texture (agricultural sector) or forest type, forest size and fragmentation (forest sector). The random value is, however, selected from a predetermined data range. Minimum and maximum scenarios have been produced during the upscaling process. They determine the upper and lower boundary of the data range. For example, soil erodibility ranges in German districts between 1 (very weak) and 5 (very strong). Thus, the Monte Carlo routine will randomly select values between 1 and 5 using the RANDBETWEEN()[18] function.

The Monte Carlo method is an appropriate tool to investigate the sensitivity of the vulnerability index to variations in the selected input variables, and also determines the underlying uncertainty in the vulnerability calculation.

7.3 Visualization and results

The final step in the mapping and interpretation of vulnerability is the visualization of the outputs. In this chapter the final composite vulnerability indicator as well as the results of the evaluation process are visualized and described.

7.3.1 Composite vulnerability index

By means of a GIS the final composite vulnerability indicator as well as its components can be mapped. In figure 7.5, the vulnerability of the forest sector to river flooding is displayed. To better structure the variability of the vulnerability index across German districts five classes have been built. The histogram of the composite indicator shows a Gaussian distribution (see Figure 7.3). By calculating equal distances of the data range the vulnerability classes were derived. The dashed lines in figure 7.3 represent the boundaries of the five classes. Low values symbolize low vulnerability while high values represent high vulnerability in a district.

The visualization of the vulnerability index results in a quite heterogeneous picture for Germany. In west and south Germany, low and intermediate vulnerability classes are dominant. By contrast, in east Germany numerous districts exhibit a high or very high vulnerability index. The highest vulnerability was calculated for districts in the 'Thüringer Wald', Brandenburg, and Mecklenburg-Vorpommern. However, the Bavarian Forest in east Bavaria and the 'Pfälzer Wald' in Rhineland-Palatinate also exhibited high vulnerabilities. The lowest vulnerability has been modelled in district-independent cities such as, for example, Munich, Magdeburg, Düsseldorf, and Hamburg. By mapping the sub-components of vulnerability exposure, susceptibility, and capacities (see Figure 7.6) the degree of a district's vulnerability can easily be related to its components. For example in the eastern parts of

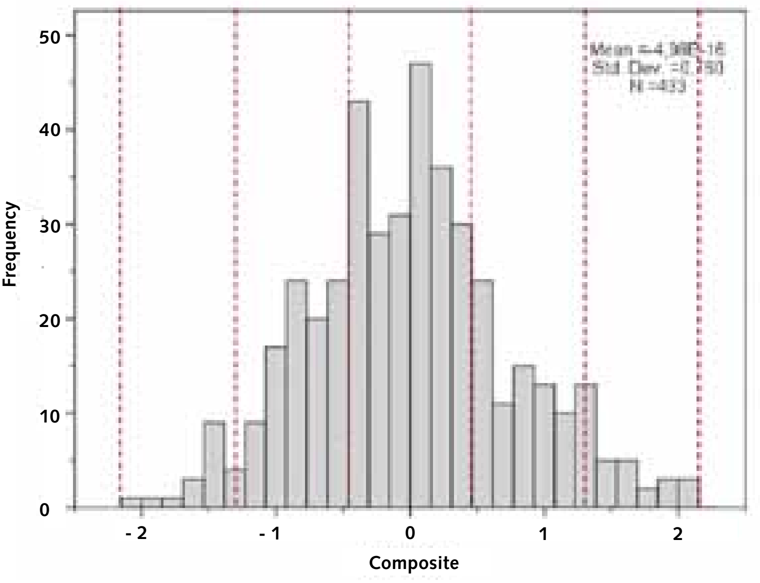
---

[18] This is a function in MS Excel 2007. In the German version of MS Excel the function is called ZUFALLSBEREICH().

Brandenburg a high exposure, very high susceptibility, and very low capacities result in very high vulnerability scores. However, in districts and district-independent cities with a very low exposure and high capacities, the vulnerability is naturally very low. Some detailed examples are provided in chapter 7.3.2. Whereas exposure and capacities show a very high variability across Germany, the susceptibility component reflects a clear dichotomy between east and west Germany. This dichotomy obviously also has implications on the overall vulnerability of German districts.

In figure 7.7 the vulnerability map for the agricultural sector is displayed. Five classes have been constructed using the same approach as for the forest sector. The frequency distribution of the vulnerability index again shows normally distributed data (see Figure 7.4). The distribution is only slightly right-skewed. Thus, equal distances are again a meaningful method of classifying the vulnerability indices. Vulnerability is ranked from very low, low, intermediate, high, and very high.

Figure 7.3: Histogram of vulnerability composite indicator of the forest sector.
Dashed lines symbolize the boundaries of the vulnerability classes

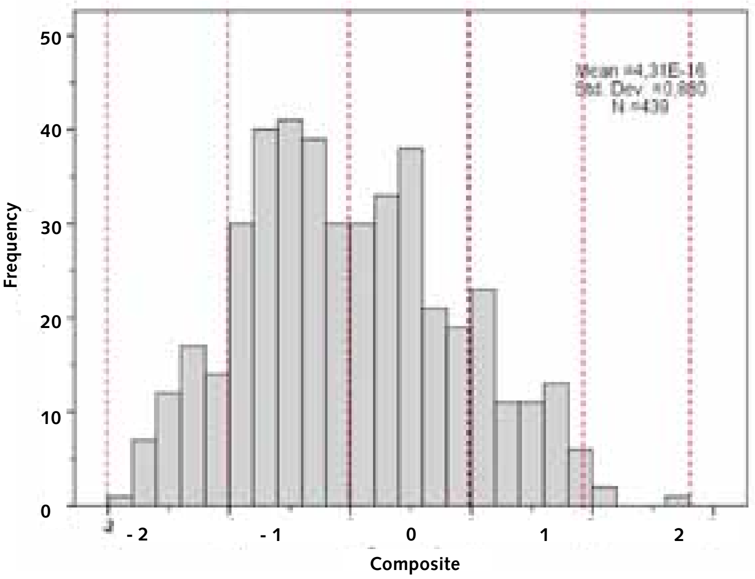


Source: Author

The vulnerability map for the agricultural sector compares the vulnerability of districts to river flooding between German districts and independent cities. A regional trend can be observed in east Germany with predominantly intermediate to very high vulnerability in the districts. The district 'Demmin' in Mecklenburg-Vorpommern has by far the highest vulnerability in Germany. It is followed by further districts in Saxony and Saxony-Anhalt. North-west Germany also has considerably high vulnerability to river flooding. Very low vulnerability has been calculated, on the other hand, for large parts of west and south Germany. In particular, the Black Forest in Baden-Württemberg and districts in the alpine uplands show very low vulnerability.

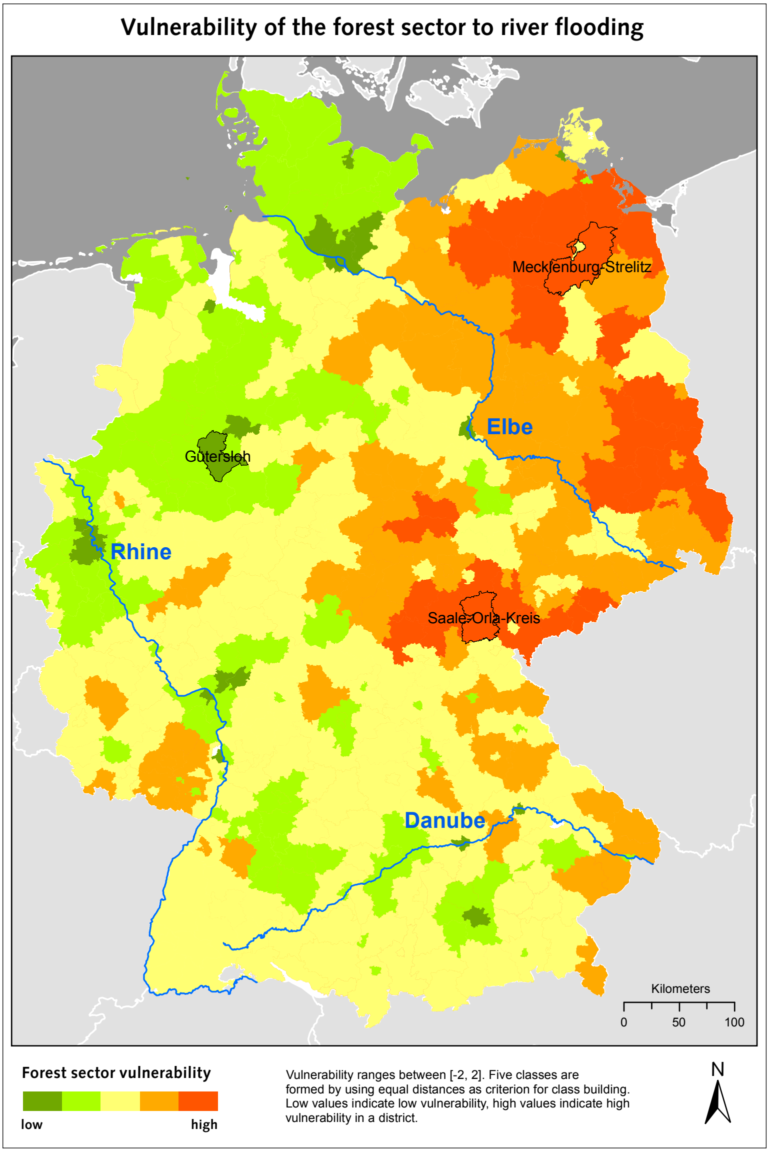
Figure 7.8 illustrates the vulnerability components for the agricultural sector that determine the score of the vulnerability index. The exposure and capacities map shows a very heterogeneous picture for Germany. Districts in Bavaria and north Germany are highly exposed, whereas along the River Rhine little exposure has been calculated. Capacities tend to be high in south and west Germany. However, only a few districts can really exhibit very high capacities. East Germany is again penalized with very low capacities in the districts. Furthermore, similar to the susceptibility map of the forest sector, a dichotomy between the 'new' and 'old' federal states can be observed. East Germany exhibits a high susceptibility, whereas other regions in Germany, except for the 'Ruhr Area', show a fairly low susceptibility.

Figure 7.4: Histogram of vulnerability composite indicator of the agricultural sector.
Dashed lines symbolize the boundaries of the vulnerability classes



Source: Author

Figure 7.5: Vulnerability map for the forest sector at district level

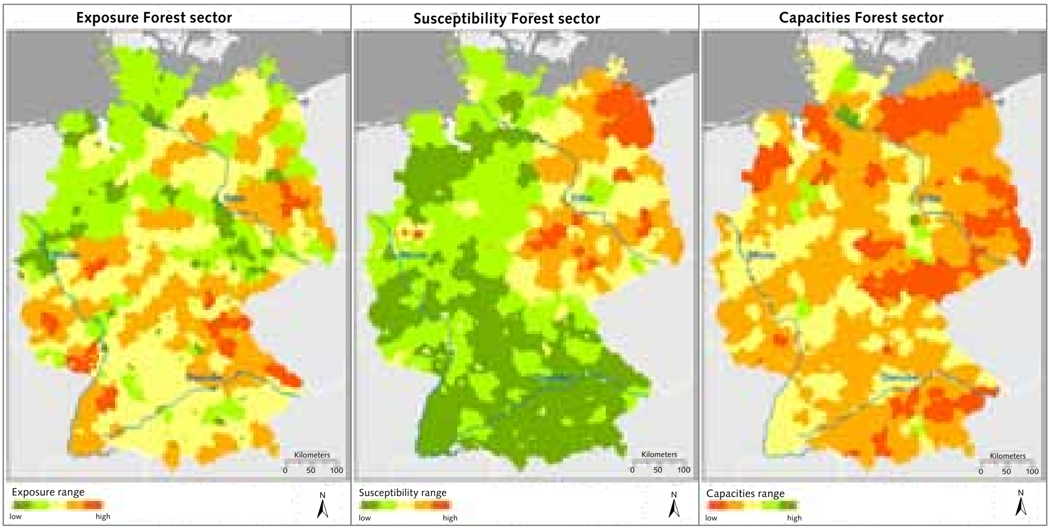


Vulnerability of the forest sector to river flooding

Vulnerability ranges between [-2, 2]. Five classes are formed by using equal distances as criterion for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Source: Author

Figure 7.6: Sub-components of vulnerability: exposure, susceptibility, and capacities of the forest sector at district level



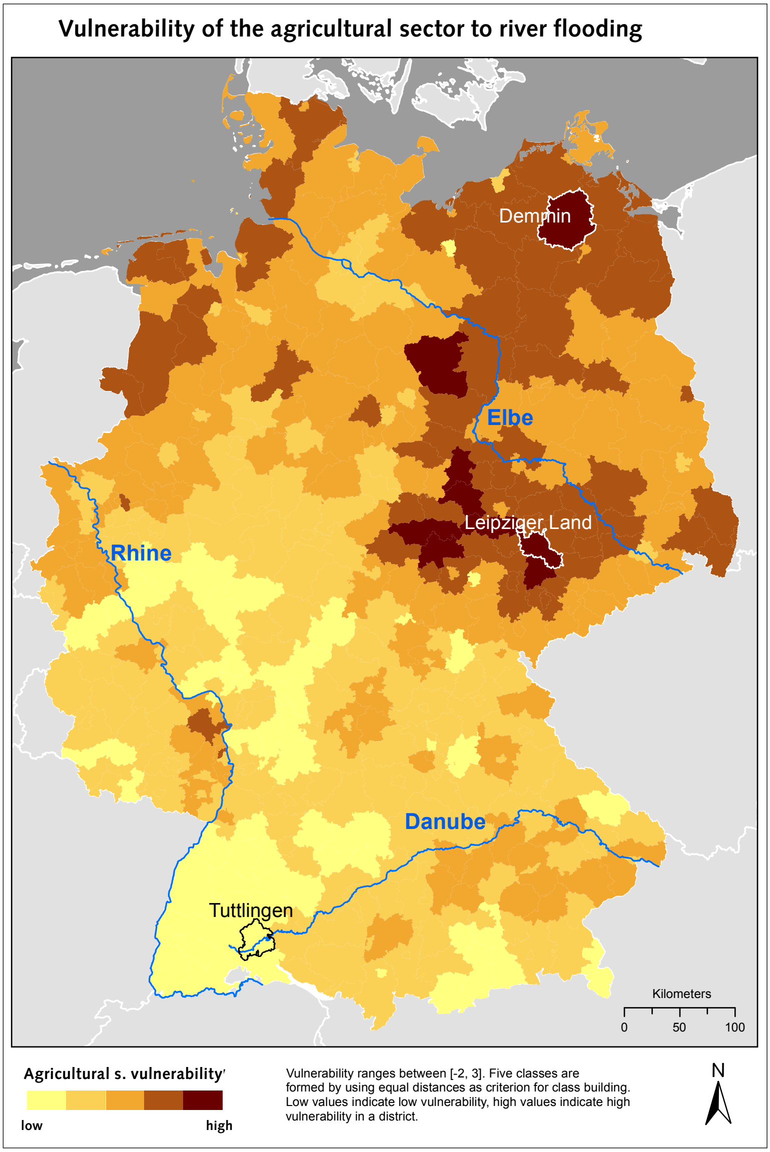
Exposure ranges between [-1, 1,5]. Five classes are formed by using eual distances as criterion for class building. Low values indicate low exposure, high values indicate high exposure in a district.

Susceptibility ranges between [-1, 1,5]. Five classes are formed by using eual distances as criterion for class building. Low values indicate low susceptibility, high values indicate high susceptibility in a district.

Capacities ranges between [-1, 1,5]. Five classes are formed by using equal distances as criterion for class building. Low values indicate low capacities, high values indicate high capacities in a district.

Source: Author

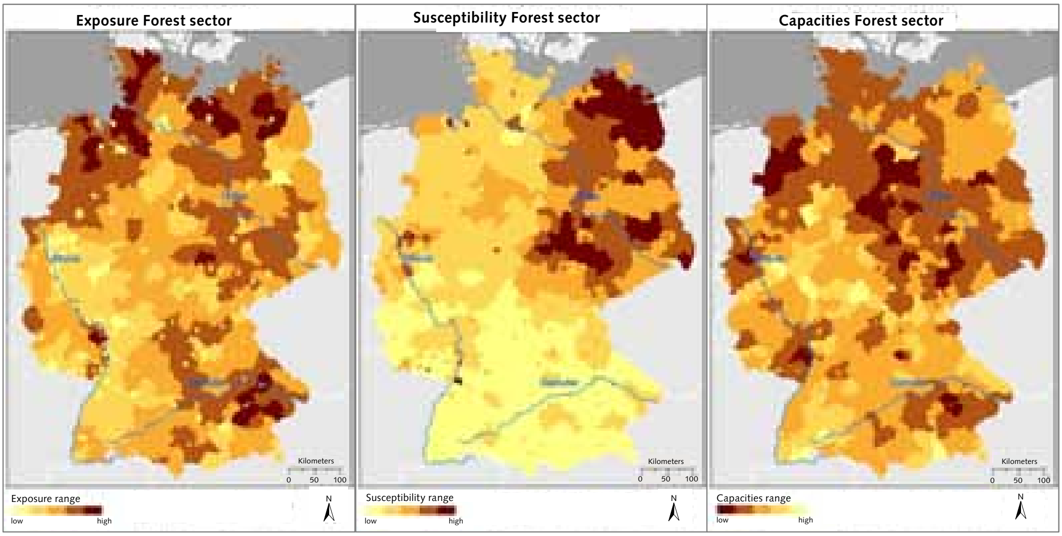
Figure 7.7: Vulnerability map for the agricultural sector at district level



Vulnerability ranges between [-2, 3]. Five classes are formed by using equal distances as criterion for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Source: Author

Figure 7.8: Sub-components of vulnerability: exposure, susceptibility, and capacities of the agricultural sector at district level



Exposure ranges between [-1, 1]. Five classes are formed by using equal distances as criterion for class building. Low values indicate low exposure, high values indicate high exposure in a district.

Susceptibility ranges between [-1, 1,5]. Five classes are formed by using equal distances as criterion for class building. Low values indicate low susceptibility, high values indicate high susceptibility in a district.

Capacities ranges between [-1, 1]. Five classes are formed by using equal distances as criterion for class building. Low values indicate capacities, high values indicate high capacities in a district.

Source: Author

7.3.2 Vulnerability analysis of selected districts

Three districts have been selected for each sector to reveal the influences and implications of the vulnerability components on the overall composite indicator.

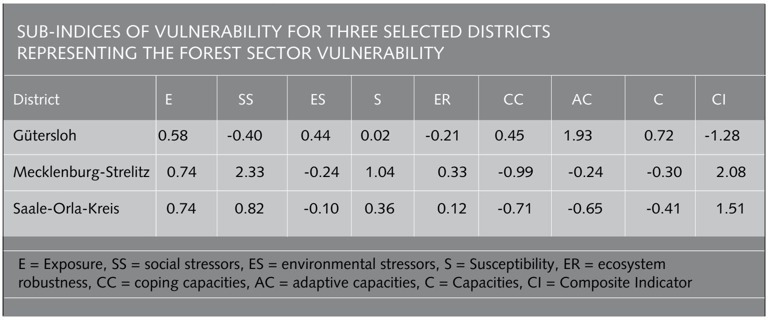
Forest sector:

Gütersloh is situated in North Rhine Westphalia and has a vulnerability index of -1.28. The lowest vulnerability rank has been assigned to this district due to its low index. The sub-indices in table 7.7 reveal that exposure in Gütersloh is very low, with an index of -0.58. By contrast, susceptibility is very close to the mean with 0.02, and capacities exhibits high values with an index of 0.72 due the district's significant adaptive capacities. Thus, a low exposure and susceptibility combined with high capacities results in a very low composite vulnerability index.

Mecklenburg-Strelitz exhibits the highest vulnerability index in Germany with 2.08. High exposure and very high level of social stressors are responsible for the maximum value. Furthermore, coping and adaptive capacities are also very low and cannot balance the already low values. Since the selected normalization method favours extreme values in the data set, the social stressor index of 2.33 has a considerable influence on the outcome. However, the approach clearly shows the weaknesses and strengths in a district.

The district Saale-Orla in Thuringia has also been assigned to the highest vulnerability class with an index of 1.51. The analysis shows that the components of exposure and susceptibility lie significantly over the mean. On the other hand, capacities in the district are pretty low at -0.41. In particular, the coping and adapting capacities contribute to the low capacities index. The consequence of low capacities and high exposure and susceptibility is a high vulnerability index.

Table 7.7: Sub-indices of vulnerability for three selected districts representing forest sector vulnerability



SUB-INDICES OF VULNERABILITY FOR THREE SELECTED DISTRICTS REPRESENTING THE FOREST SECTOR VULNERABILITY

District	E	SS	ES	S	ER	CC	AC	C	CI
Gütersloh	0.58	-0.40	0.44	0.02	-0.21	0.45	1.93	0.72	-1.28
Mecklenburg-Strelitz	0.74	2.33	-0.24	1.04	0.33	-0.99	-0.24	-0.30	2.08
Saale-Orla-Kreis	0.74	0.82	-0.10	0.36	0.12	-0.71	-0.65	-0.41	1.51

E = Exposure, SS = social stressors, ES = environmental stressors, S = Susceptibility, ER = ecosystem robustness, CC = coping capacities, AC = adaptive capacities, C = Capacities, CI = Composite Indicator

Source: Author

Agricultural sector:

Tuttlingen is situated in Baden-Württemberg in south Germany and represents a district with very low vulnerability to river flooding. The vulnerability index of -1.77 is very low due to the marginal susceptibility and strong capacities in the district. Therefore, the exposure of 0.34 does not have strong implications on the composite indicator.

The opposite can be observed in the district of Demmin in Mecklenburg-Vorpommern. A very high exposure coupled with quite high susceptibility and a low level of capacities results in one of the highest vulnerability indices in Germany. Again it is the social stressor index which exhibits a very high value of 2.69 and thus has a significant influence on the vulnerability index.

The highest vulnerability class has also been assigned to the district Leipziger Land in Saxony. Here the exposure is quite low, close to the mean of zero. However, high susceptibility and low capacities indices cause significantly high vulnerability in the district. Not only social but also environmental stressors are responsible for the high susceptibility index, and the capacities components all show very weak capacities. Therefore, the combination of intermediate exposure, high susceptibility, and low capacities results in a very high vulnerability index.

Table 7.8: Sub-indices of vulnerability for three selected districts representing agricultural sector vulnerability

SUB-INDICES OF VULNERABILITY FOR THREE SELECTED DISTRICTS REPRESENTING THE AGRICULTURAL SECTOR VULNERABILITY

District	E	SS	ES	S	ER	CC	AC	C	CI
Tuttlingen	0.34	-1.06	-0.27	-0.66	0.75	0.74	0.81	0.77	-1.77
Demmin	1.18	2.69	-0.12	1.28	-0.49	-0.86	0.42	-0.31	2.77
Leipziger Land	0.19	1.68	1.03	1.36	-0.63	-0.37	-0.48	-0.49	2.04

E = Exposure, SS = social stressors, ES = environmental stressors, S = Susceptibility, ER = ecosystem robustness, CC = coping capacities, AC = adaptive capacities, C = Capacities, CI = Composite Indicator

Source: Author

7.3.3 Results of the evaluation process

The reliability and soundness of the vulnerability index is evaluated by robustness tests, susceptibility, and uncertainty analyses. The results of the evaluation are presented in this section.

7.3.3.1 Robustness tests

As described in chapter 7.2.5, different normalization, weighting, and aggregation methods have been calculated and compared to check the robustness of the vulnerability composite indicator. In figure 7.9 and figure 7.10 the outcome of the vulnerability calculations is visualized for all the different calculation scenarios. In the first row the different normalization techniques are displayed; in the second row three weighting techniques are compared; and in the last row two aggregation methods are juxtaposed. Just from a rough visual interpretation, the same hot spot regions can be detected in all maps for the forest and for the agricultural sectors despite the different calculation models. Although variations across districts can certainly be observed, the vulnerability maps exhibit the same trends and patterns. For the forest sector only the geometric aggregation shows some obvious changes. An overall shift from lower to higher vulnerability ranks has taken place. Districts with low and very low vulnerability are rare. However, this is not the case for the agricultural sector. Here the differences between the calculation scenarios are even less significant. Table 7.9 displays the mean volatility of the rankings across districts measured by the standard deviation. Volatility is measured by the standard deviation of the ranks for each district (see Groh et al. 2007).

The volatility of the forest sector ranks ranges between 0.25 and 0.42. This means that different normalization techniques produce the fewest changes in the vulnerability rankings, whereas the two aggregation methods cause more variations. This confirms the observations made by visual interpretation. The volatility within the agricultural sector is lower than for the forest sector. It ranges between 0.16 and 0.4 and is again strongest for the aggregation techniques. The mean vola-

Table 7.9: Mean volatility between different vulnerability scenarios

MEAN VOLATILITY BETWEEN DIFFERENT VULNERABILITY SCENARIOS				
Sector	Mean Volatility			
	Normalization	Weighting	Aggregation	Total
Forest sector	0.25	0.30	0.42	0.47
Agric. sector	0.16	0.24	0.40	0.35

Source: Author

tility for all six different scenarios is 0.47 and 0.35. Thus, ranks change very little with the different approaches.

7.3.3.2 Sensitivity and uncertainty analysis

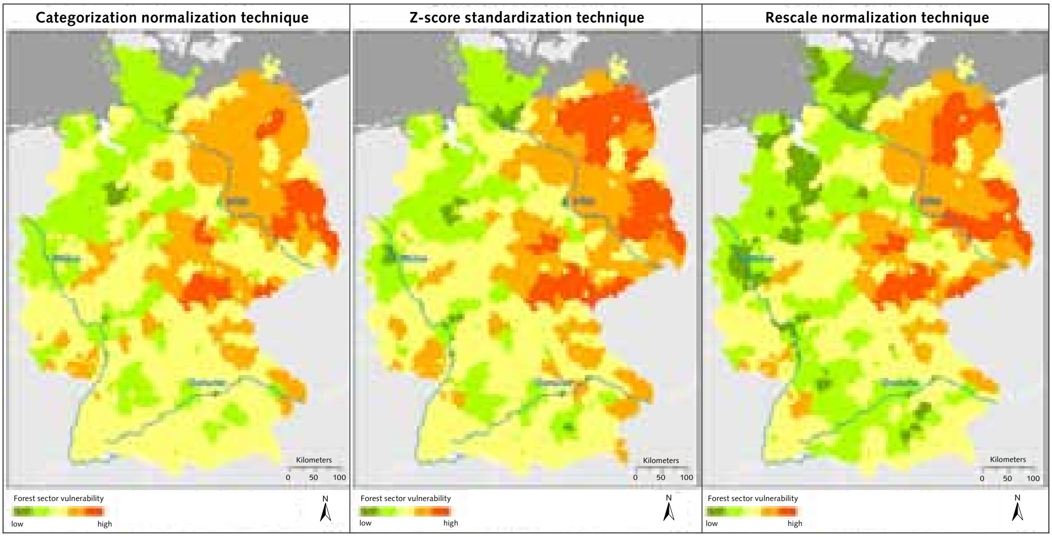
For both sectors all input variables (or indicators) have been investigated for correlations with the vulnerability composite indicator. Figure 7.11 and figure 7.12 display the result of the correlation analysis for the forest and agricultural sector. For the forest sector the coefficient of determination r^2 ranges between 0.005 and 0.265. This means that only a very low percentage of the variance in the dependent variable can be explained by the regression equation. The indicators with the highest influence on the vulnerability composite indicator are forest rate ($r^2 = 0.254$) and GDP per capita of districts ($r^2 = 0.265$).

A correlation analysis for the agricultural sector produces coefficients (r^2) between 0.001 and 0.48. Unemployment rate and the composite indicator exhibit the strongest correlation, with $r^2 = 0.48$. The indicator farmland rate follows with $r^2 = 0.32$. The other indicators are not significantly correlated with the vulnerability composite.

Thus, the vulnerability indicator is definitely sensitive to various input variables. However, the correlations are not significantly high and exist only for a very limited number of variables.

After testing the correlations of certain indicators and the composite, a sensitivity test has been carried out by changing or excluding certain variables and calculating the mean volatility of the resulting vulnerability ranks. Table 7.10 presents the mean volatility of six different scenarios compared with the original vulnerability calculation of the forest sector. The mean volatility across all German districts ranges between 0.05 and 0.21.

Figure 7.9: Forest sector vulnerability calculated by using different normalization, weighting, and aggregation methods



Categorization normalization technique

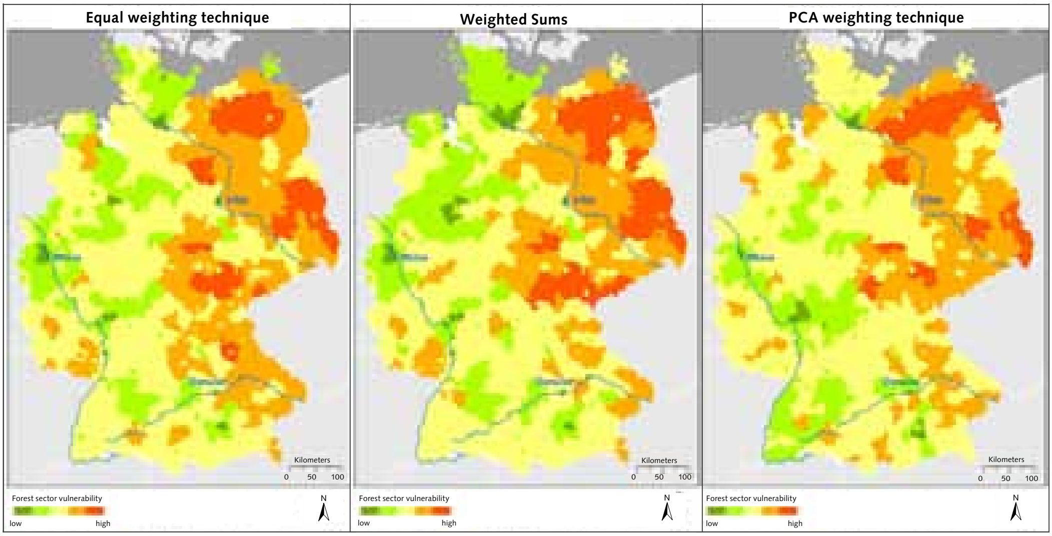
Z-score standardization technique

Rescale normalization technique

Vulnerability is ranked from 1 to 5. The ranks represent the five vulnerability classes. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [-2,2]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [0,1]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.



Equal weighting technique

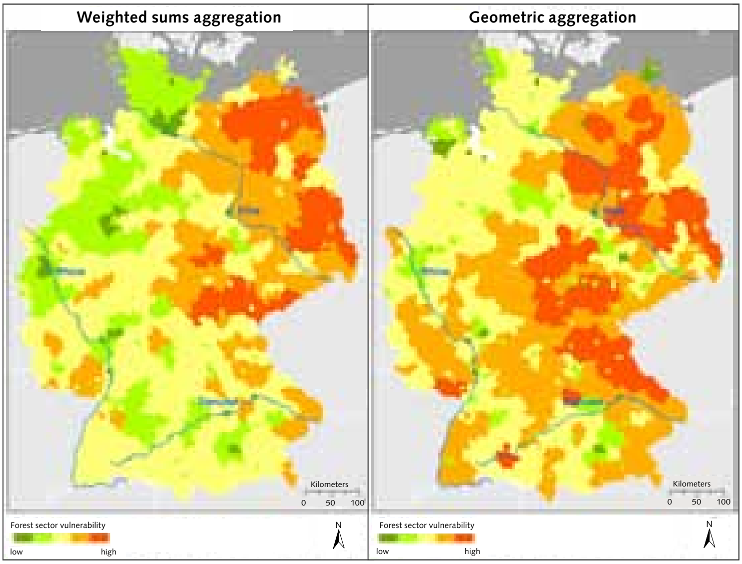
Weighted Sums

PCA weighting technique

Vulnerability ranges between [-3,3]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [-2,2]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [-1,1]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.


Weighted sums aggregation

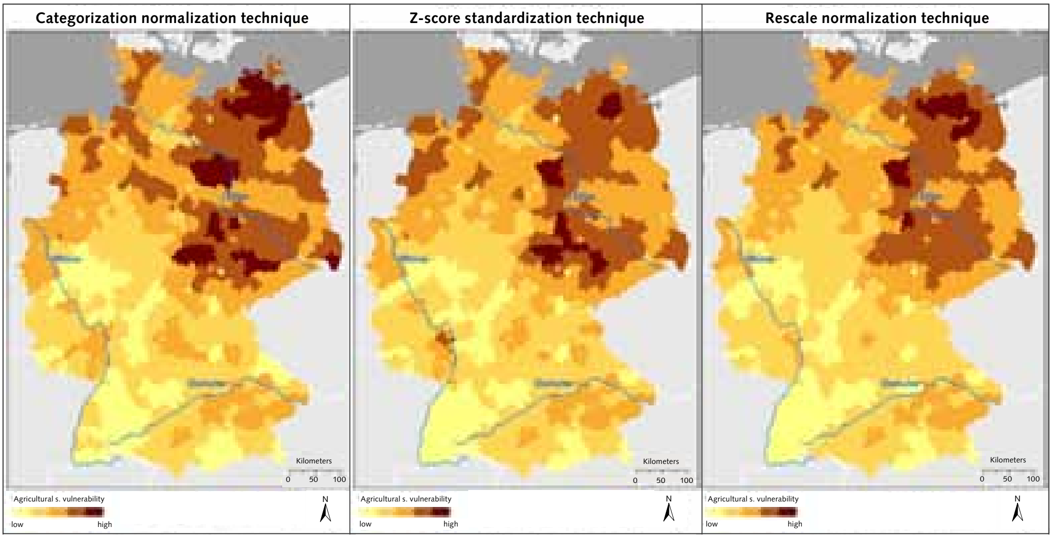
Geometric aggregation

Vulnerability ranges between [-2,2]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [0,1]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Source: Author

Figure 7.10: Agricultural sector vulnerability calculated by using different normalization, weighting, and aggregation methods



Categorization normalization technique

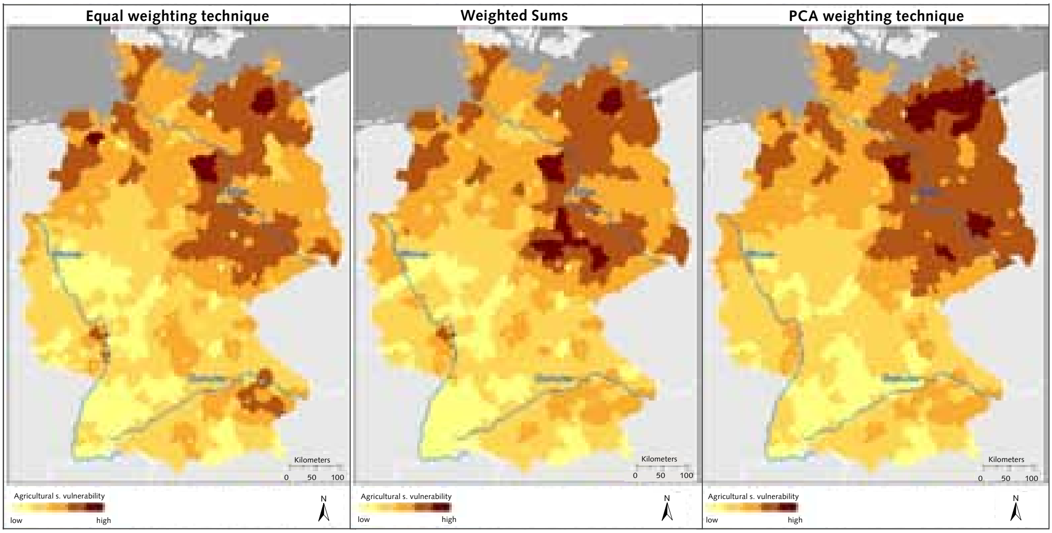
Z-score standardization technique

Rescale normalization technique

Vulnerability is ranked from 1 to 5. The ranks represent the five vulnerability classes. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [-2,3]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [0,1]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.



Equal weighting technique

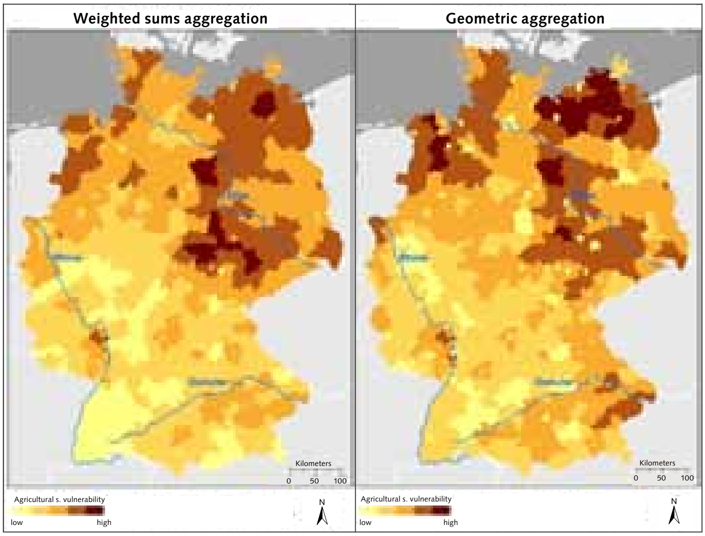
Weighted Sums

PCA weighting technique

Vulnerability ranges between [-3,4]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [-2,3]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [-1,1]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.



Vulnerability ranges between [-2,3]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Vulnerability ranges between [0,1]. Five classes are formed by using equal distances as criteria for class building. Low values indicate low vulnerability, high values indicate high vulnerability in a district.

Source: Author

Table 7.10: Mean volatilities of six scenarios with the original approach for the forest sector

MEAN VOLATILITIES OF SIX SCENARIOS WITH THE ORIGINAL APPROACH FOR THE FOREST SECTOR						
Changed variable	Excl. GDP p. c. FS	Mean GDP p. c. FS	Excl. damage rate	Mean damage rate	Excl. ggk	Mean ggk
Volatility	0.05	0.06	0.16	0.13	0.21	0.08

Source: Author

Four additional scenarios have also been calculated for the agricultural sector. Here the volatility ranges between 0.02 and 0.06 (see Table 7.11).

Table 7.11: Mean volatilities of four scenarios with the original approach for the agricultural sector

MEAN VOLATILITIES OF FOUR SCENARIOS WITH THE ORIGINAL APPROACH FOR THE AGRICULTURAL SECTOR				
Changed variable	Excl. GDP p. c. FS	Mean GDP p. c. FS	Excl. ggk	Mean ggk
Volatility	0.04	0.02	0.05	0.06

Source: Author

The maximum volatility in a district for the forest and agricultural sectors accounts for 0.76, which means that the ranks of the original approach and the scenarios differ only in one score in the worst case.

Altogether, the mean volatilities in both sectors are considered as very low and show that the sensitivity of the composite indicator to the changed or excluded variables is negligibly low.

Monte Carlo Analysis:

The MCA has been carried out to check the sensitivity of the composite indicator towards variations in the soil input data (agricultural sector) and forest input data (forest sector). After calculating vulnerability 5000 times for each district with randomly selected data within a certain data range, a frequency distribution was generated with the outcome data. Figure 7.13 and figure 7.14 show the histograms of four selected districts in Germany for each sector. The original calculated vulnerability index is marked by a blue bar in each histogram. The distributions correspond to a Gaussian distribution.

For the forest sector the data range of all simulated vulnerability indices does not exceed 0.16. The standard deviation is approximately 0.03 across all districts in Germany. By determining the range of the standard deviation around the mean [μ-s, μ+s], the reliability of the original calculated composite vulnerability index could be estimated. Calculations showed that the original composite lies within the range of [μ-s, μ+s] with a probability of over 70 %. Table 7.12 shows the descriptive statistics for four selected districts. The minimum and maximum values of the Monte Carlo simulation are presented as well as the original vulnerability index (VI). Range and standard deviation (SD) complete the table. The range of uncertainty for the district 09188000 ("Starnberg") is 0.065 to 0.122, which is equivalent to a relative range of -27 to +46 % as compared to the original vulnerability index. Across all districts in Germany a mean relative range of -22 and +25 % has been calculated.

Table 7.12: Descriptive statistics of results from the Monte Carlo Simulations for the forest sector

DESCRIPTIVE STATISTICS OF RESULTS FROM THE MONTE CARLO SIMULATIONS FOR THE FOREST SECTOR

AGS	Minimum	VI	Maximum	Range	SD
05162000	-0.054	0.008	0.105	0.159	0.031
08127000	0.206	0.287	0.366	0.160	0.030
09188000	0.065	0.122	0.226	0.161	0.030
13053000	0.495	0.584	0.655	0.160	0.029

Source: Author

The same calculations have been conducted for the agricultural sector. The range between minimum and maximum scenario does not exceed 0.195 for all districts. The SD averages 0.04. Furthermore, 50 % of the original vulnerability indices are located within the range of the standard deviation around the mean. In table 7.13 the descriptive statistics of the Monte Carlo simulations for four selected districts are presented. For instance, the range of uncertainty of district 03453000 ("Cloppenburg") is 0.354 to 0.548. With an original vulnerability index of 0.520 this is equivalent to a relative range of -22 to +4 %. The relative range across all districts averages from -28 to +18 %.

Table 7.13: Descriptive statistics of results from the Monte Carlo Simulations for the agricultural sector

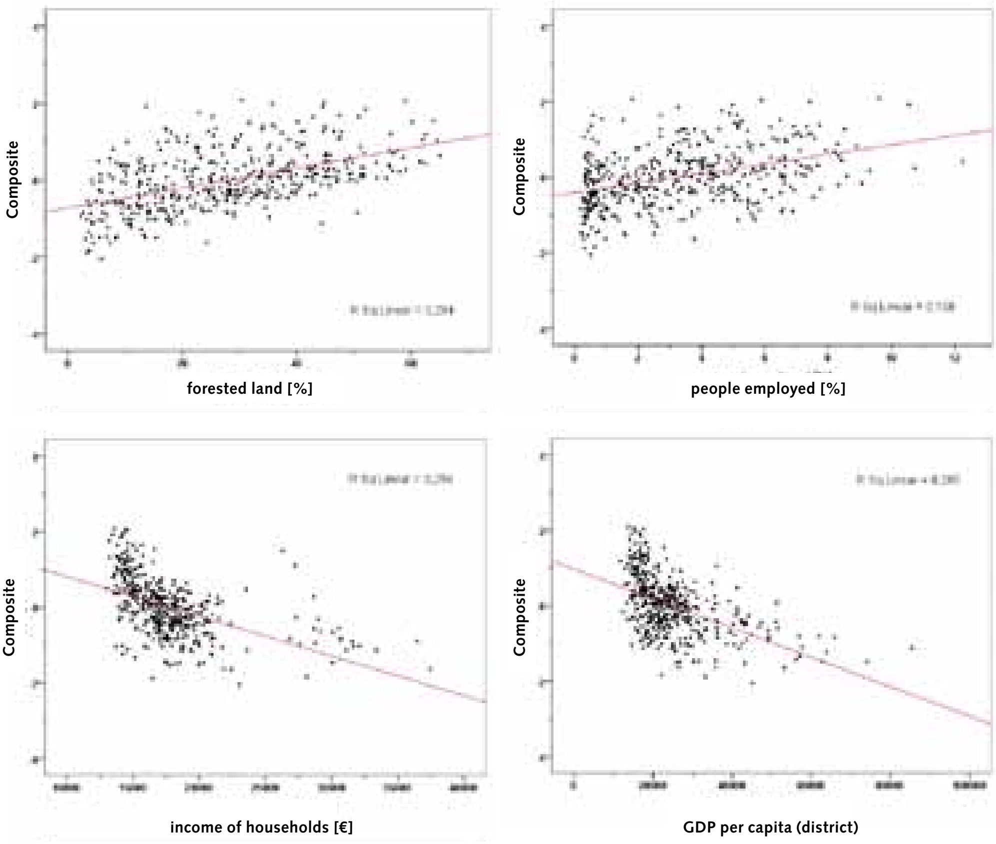
DESCRIPTIVE STATISTICS OF RESULTS FROM THE MONTE CARLO SIMULATIONS FOR THE AGRICULTURAL SECTOR

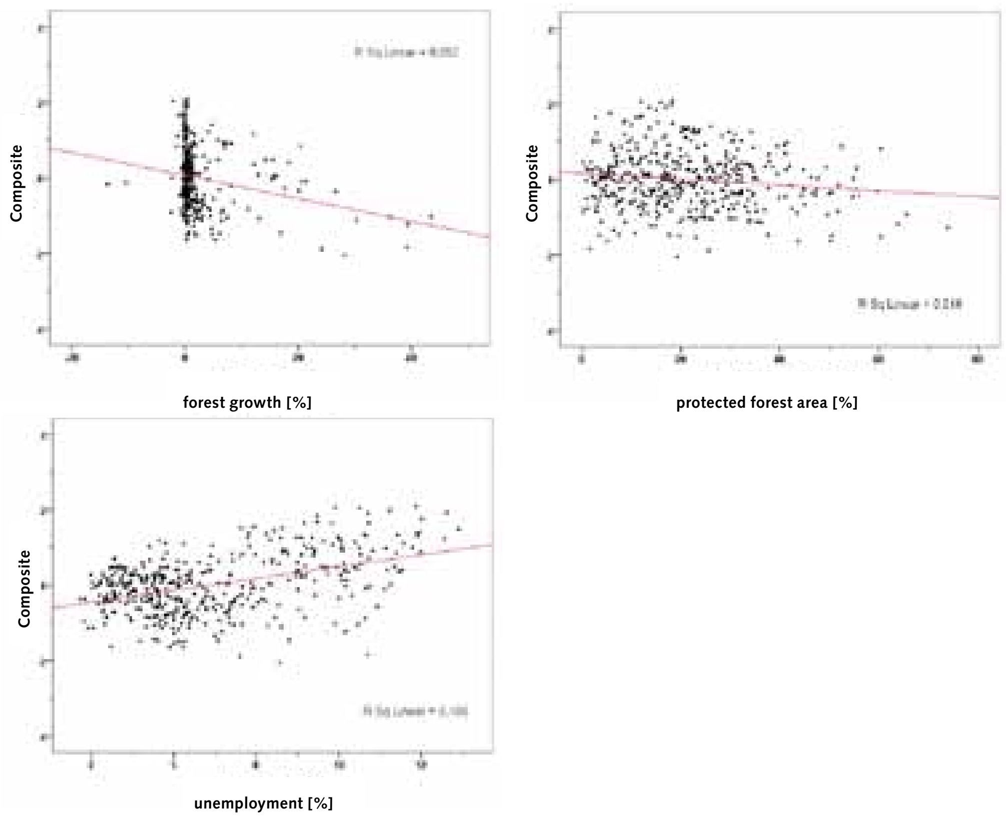
AGS	Minimum	VI	Maximum	Range	SD
03453000	0.354	0.520	0.548	0.194	0.041
05911000	0.069	0.153	0.264	0.195	0.040
08136000	-0.044	-0.017	0.150	0.194	0.040
09472000	0.049	0.188	0.244	0.195	0.039

Source: Author

In conclusion, the sensitivity and uncertainty analyses of both sectors revealed that the vulnerability composite does indeed face considerable sensitivities and uncertainties. Sensitive input variables are, for example, the indicators of the subcomponent exposure and the indicator unemployment rate of districts. However, the sensitivity of the vulnerability composite to indicators that were scaled to district level appeared very low. Since lower weights were assigned to these indicators, the result is not unexpected. The Monte Carlo analysis conducted by varying soil and forest input data has produced 2000 vulnerability indices for each district. The results show that although the range between the minimum and maximum scenarios is quite small, with values of 0.16 and 0.19, changes of the vulnerability ranks are possible. Thus, the composite reacts sensitively to variations in soil and forest input data. Furthermore, by calculating the possible range of vulnerability indices per district, the range of uncertainty can easily be determined.

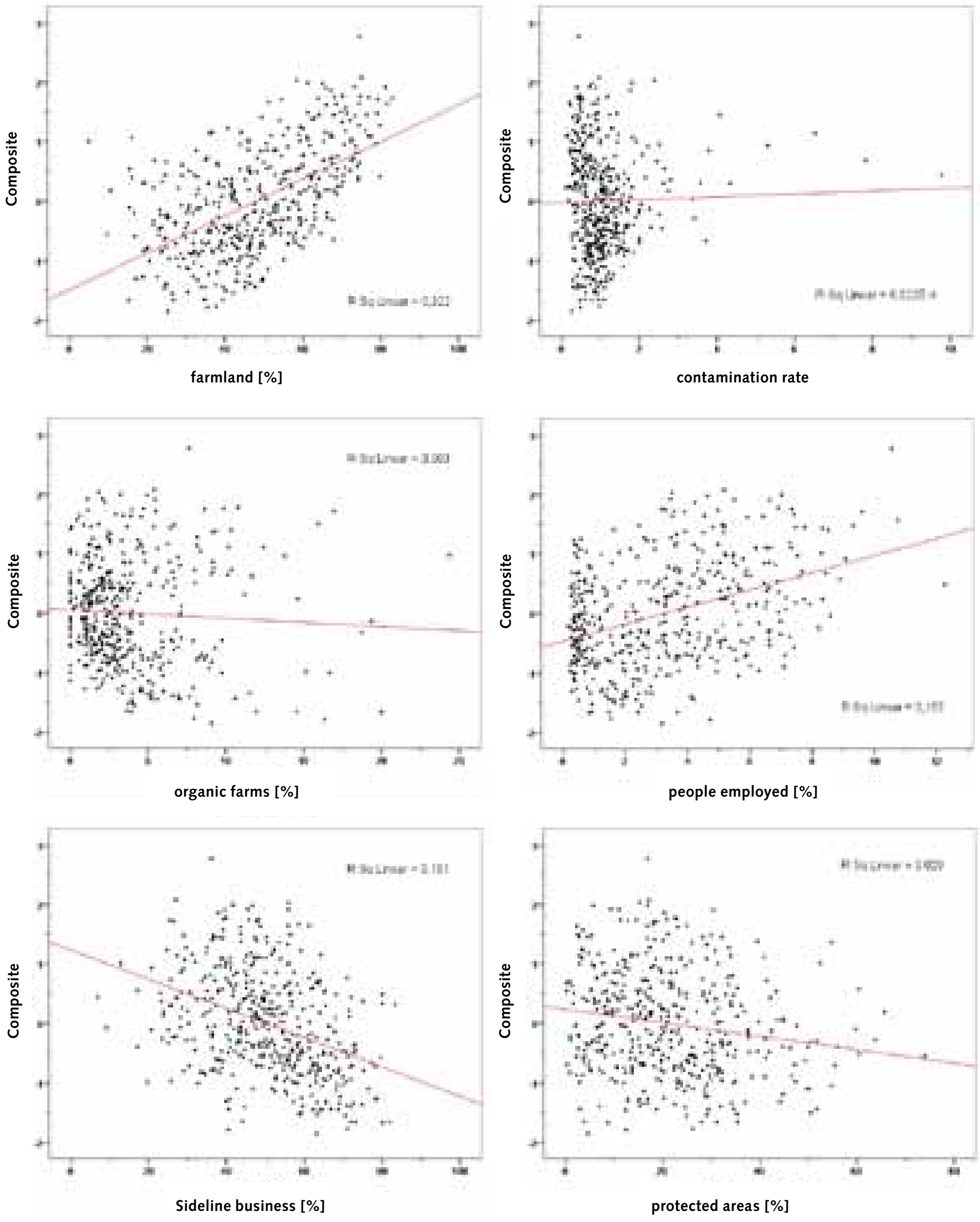
Figure 7.11: Correlation between input variables and composite indicator for forest sector

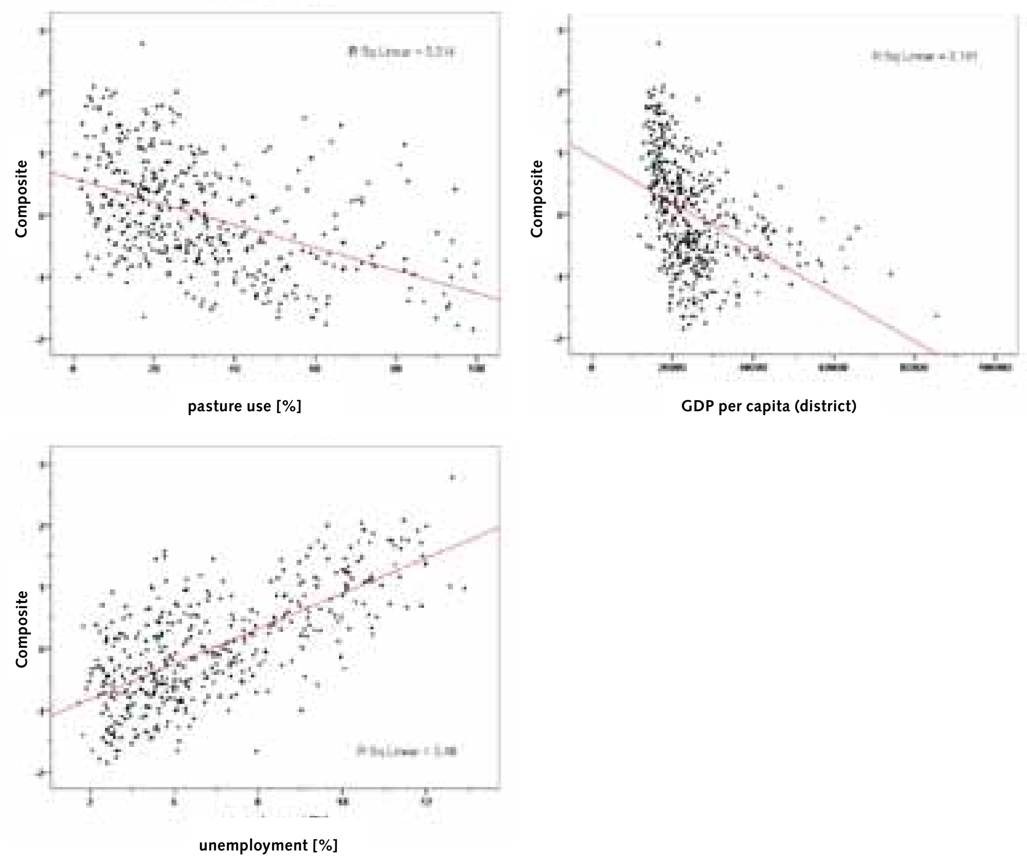




Source: Author

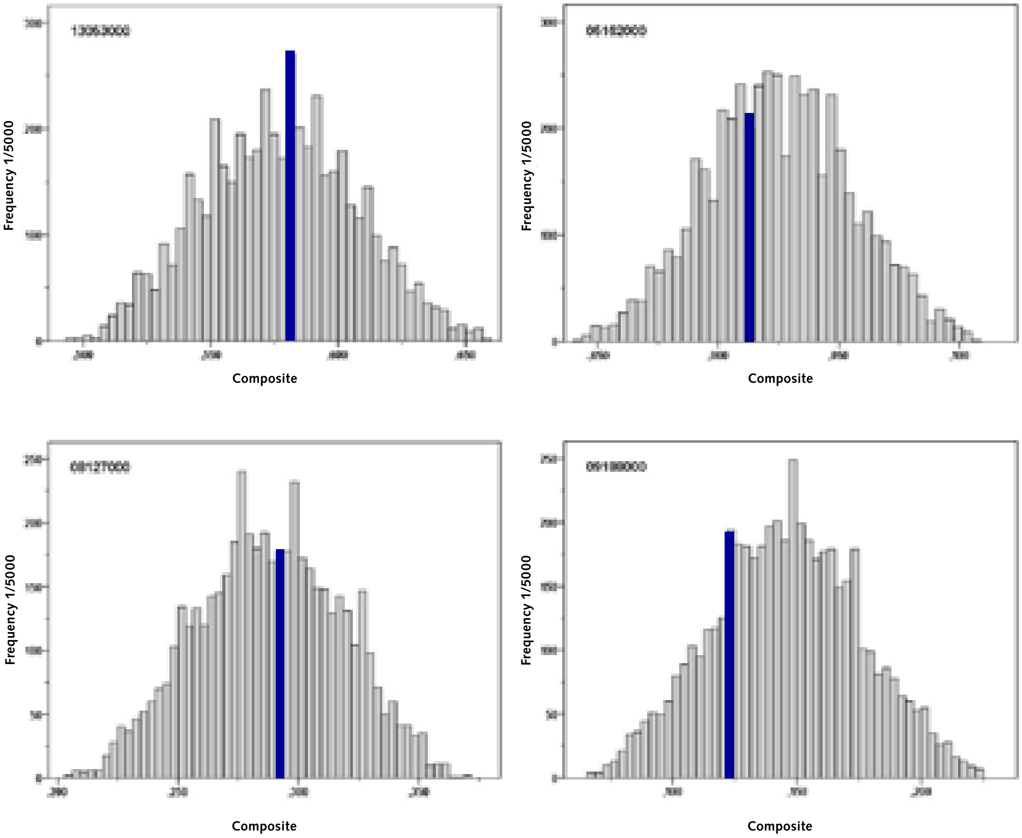
Figure 7.12: Correlation between input variables and composite indicator for agricultural sector





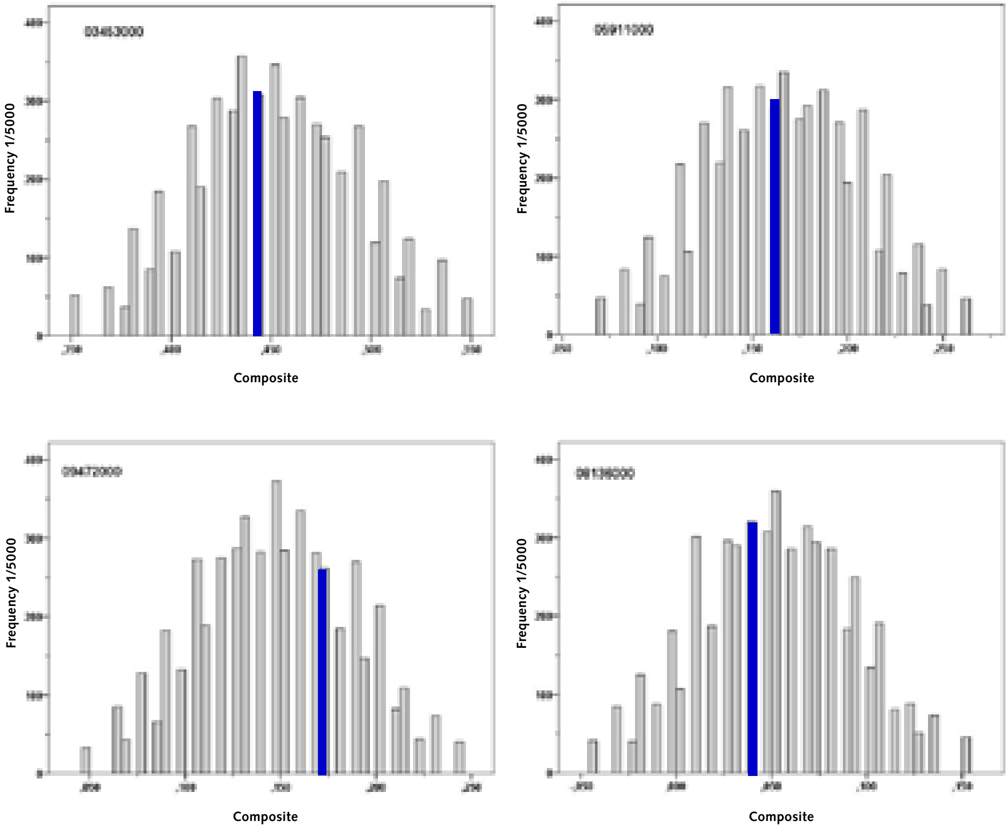
Source: Author

Figure 7.13: Histogram of Monte Carlo simulation for four selected districts (forest sector)



Source: Author

Figure 7.14: Histogram of Monte Carlo simulation for four selected districts (agricultural sector)



Source: Author

7.4 Mapping flood risk

Following the conceptual and theoretical framework determined in chapter 3, flood disaster risk is defined by the two components of hazard and vulnerability at a certain place. In this section we want to show how to map flood risk by means of the calculated vulnerability index and the hazard characteristic 'inundation area'. Other hazard characteristics such as flow velocity and flood duration are not included in this approach due to a lack of data and information. Flood risk is calculated and mapped with one single hazard characteristic to show, first, how to combine the two components of hazard and vulnerability, and second, to demonstrate how the vulnerability composite can be used for flood disaster management.

7.4.1 Method and data

Flood risk calculations are conducted for the river Rhine and Elbe. Beside the vulnerability index, flood hazard maps are needed to carry out the risk analysis. Therefore, two additional data sets have been gathered. First the Elbe Atlas (see www.ella-interreg.org), which contains HQextreme and HQ100 data for the river Elbe from the Czech Republic to Schleswig-Holstein, and second, the Rhine Atlas (ICPR 2001) containing hazard maps for the Rhine river from the 'Bodensee' to its estuary in the North Sea. All hazard maps exist in a GIS shape format and can therefore easily be mapped and processed in a GIS. For the flood risk calculations only hazard maps of extreme flood events have been used. Extreme hazard maps are important as they indicate the inundation extent if flood protection barriers fail or are overtopped. Although these events are very rare, they have to be taken into account for preventive strategies and emergency planning, since extreme events can cause the worst and most unexpected damage and losses.

The hazard maps have been intersected with the districts to calculate the extent to which the district area could be flooded by an extreme event. Following the results of the scenarios of the Elbe and Rhine Atlas up to 70 % of district area can be flooded in the case of an extreme event along the rivers Rhine and Elbe. The districts are ranked in five categories regarding their potential to be inundated more or less extensively. The ranks are calculated and assigned either on river basin (regional) level or on a nationwide level. This approach uses the river basin level, since disaster management usually focuses on a certain region or river system. Thus, the comparison of ranks across districts in a specific region is even more important than the use of the same hazard ranks across the whole of Germany. However, this depends on the objective of the respective study/analysis and has to be decided from case to case. In figure 7.15 and figure 7.16 the affected districts along the rivers Elbe and Rhine are mapped showing the severity with which single districts might be flooded. Light blue colours indicate a low percentage; dark blue colours a high percentage of flooded area in a district. The maximum extent of inundation accounts for 70 % along the Rhine River and for 45 % along the river Elbe. Five classes are formed for each river system by using equal distances as a criterion for class building. According to the vulnerability ranking, the classes are ranked from 1 (very low) to 5 (very high) (see Table 7.14).

Table 7.14: Hazard and vulnerability ranking

HAZARD AND VULNERABILITY RANKING					
	Very low	Low	Intermediate	High	Very high
Hazard	1	2	3	4	5
Vulnerability	1	2	3	4	5

Source: Author

Subsequently, the final risk index per district is calculated by multiplying vulnerability and hazard ranks. The risk index is finally mapped in five classes by using natural breaks (see Table 7.15).

Table 7.15: Risk class building

RISK CLASS BUILDING					
	Very low	Low	Intermediate	High	Very high
Risk Index	1-5	6-10	11-15	16-20	21-25
Risk Class	1	2	3	4	5

Source: Author

This facilitates the fast and simple detection of hot spots and critical regions. Table 7.16 gives four examples for the calculation of the flood disaster risk index and its further processing.

Table 7.16: Risk calculation for four example districts

RISK CALCULATION FOR FOUR EXEMPLARY DISTRICTS				
	Wittenberg	Stendal	Havelland	Anhalt-Zerbst
Vuln. Class	3	5	3	2
Hazard Class	4	5	1	4
Risk Index	12	25	3	8
Risk Class	4	5	1	3

Source: Author

7.4.2 Results

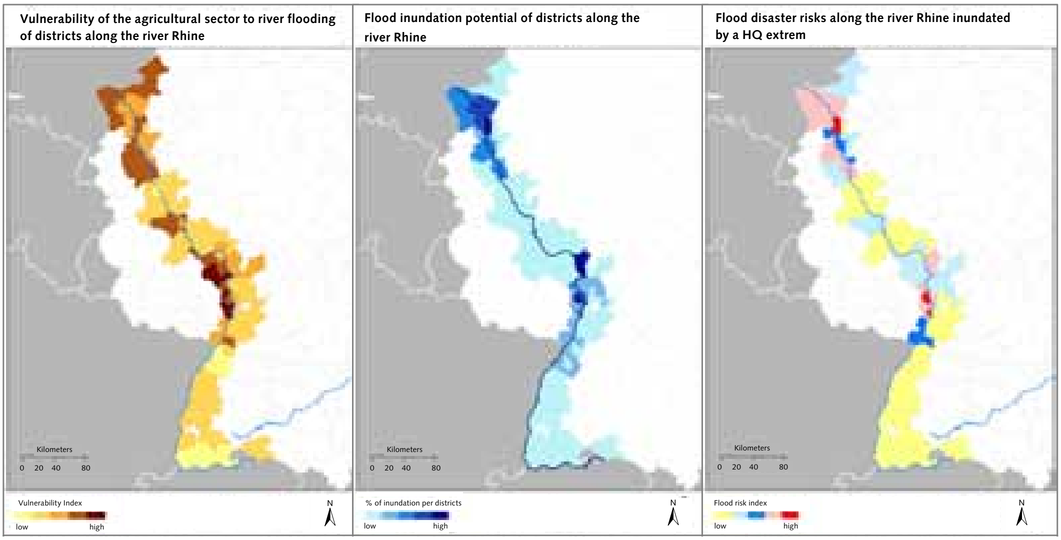
The result of the flood risk calculation for the agricultural sector is displayed in figure 7.15. For the rivers Rhine and Elbe two different calculations have been carried out. The upper three maps show the vulnerability, inundation potential, and flood disaster risk for numerous districts along the Elbe River in Saxony and Saxony-Anhalt. The districts 'Stendal' and 'Schönebeck' exhibit the highest flood disaster risk potential among the mapped districts. A maximum inundation of approximately 40 % during a HQextreme and a very high vulnerability index are responsible for the high disaster risk index in comparison to the other districts in the Elbe river basin. However, districts such as Wittenberg and Jerichower Land also face a considerably high disaster risk in the case of extreme flooding.

In the lower part of figure 7.15, vulnerability, hazard, and risk are mapped for all districts in the Rhine River basin that can be affected by an HQextreme. Large parts of the Upper Rhine show very low flood disaster risk. Only in the Rhine-Neckar region do districts such as Speyer and Frankenthal exhibit high and very high risk indices. The Lower Rhine is characterized by a very heterogeneous risk potential across the districts. The district-independent city 'Duisburg' has the highest disaster risk index and is surrounded by other districts with significantly high risk potentials, such as Kleve and Wesel. Since almost 70 % of Duisburg's area might be flooded and vulnerability is at an intermediate level, flood risk is evaluated as very high.

Forest sector vulnerability, inundation potential, and flood disaster risk have also been mapped. In figure 7.16 the results are visualized. Again the upper maps show the Elbe basin, whereas the lower maps present the Rhine basin. Along the Elbe River the districts Wittenberg, Jerichower Land, and Stendal exhibit the highest flood risk index. In these districts up to 42 % of the area might be inundated. Combined with high vulnerabilities the disaster risk potential is very high. Duisburg and Frankenthal are again the districts with the highest risk index in the Rhine basin. Kleve, Wesel, Speyer, and Mannheim are also hot spots with regard to the disaster risk potential of the forest sector. In comparison to the agricultural sector, the Upper Rhine has a higher risk potential due to the higher vulnerabilities in the districts. However, the hot spot regions remain the Rhine-Necker region and the Lower Rhine close to the Dutch border.

Flood disaster risk has been determined using a relative and comparative approach. The purpose was to provide a comparison of risk potentials in a specific region or river basin. However, it is also possible to compare disaster risk across districts of several river basins. The calculations have to be slightly modified by developing a Germany-wide vulnerability and hazard ranking.

Figure 7.15: Presentation of vulnerability, hazard, and risk maps for the rivers Elbe and Rhine regarding the agricultural sector


Vulnerability of the agricultural sector to river flooding of districts along the river Rhine

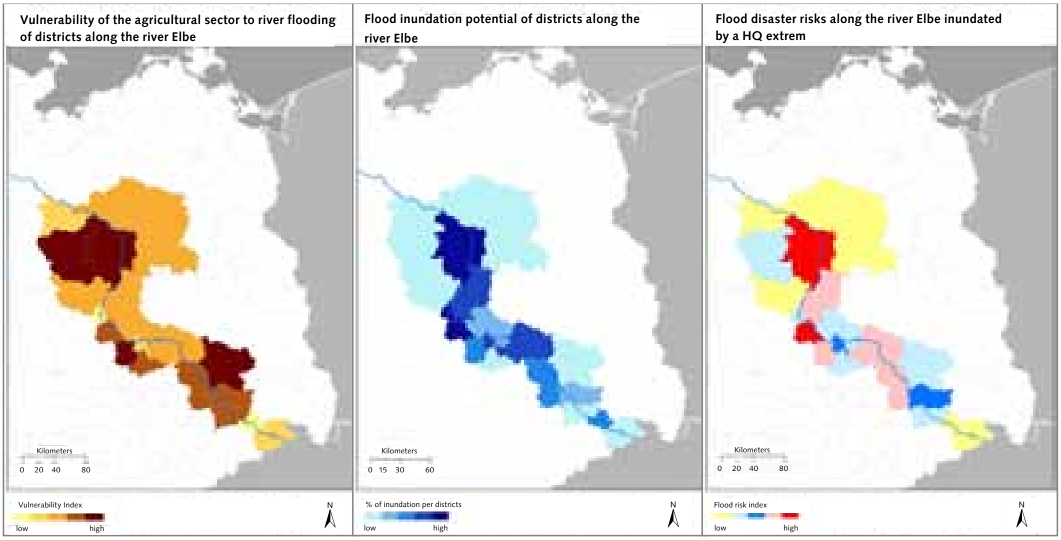
Flood inundation potential of districts along the river Rhine

Flood disaster risks along the river Rhine inundated by a HQ extrem

Vulnerability ranges between [-2,1]. Five classes are built by using equal distances of the data range. Low values indicate low vulnerability, high indices high vulnerability in a district.

Percentage ranges from 0 to 70 %. Five classes were built by using equal distances as criterion for class building.

Flood risk index has been ranked in five classes. Natural breaks are used to build classes. A low index indicates low flood risk, a high index means high flood risk.


Vulnerability of the agricultural sector to river flooding of districts along the river Elbe

Flood inundation potential of districts along the river Elbe

Flood disaster risks along the river Elbe inundated by a HQ extrem

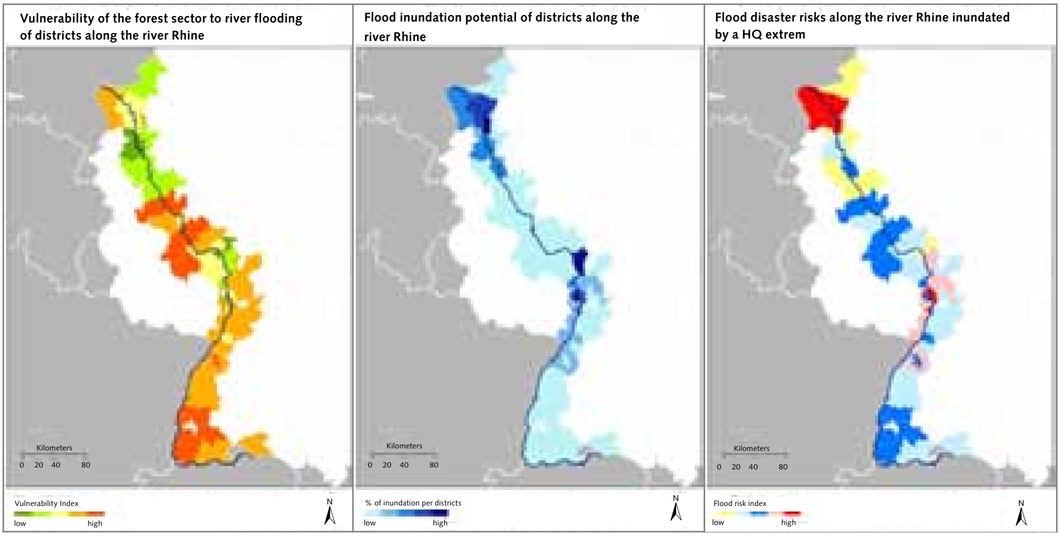
Vulnerability ranges between [0,2]. Five classes are built by using equal distances of the data range. Low values indicate low vulnerability, high indices high vulnerability in a district.

Percentage ranges from 0 to 45 %. Five classes were built by using equal distances as criterion for class building.

Flood risk index has been ranked in five classes. Equal distances are used to build classes. A low index indicates low flood risk, a high index means high flood risk.

Source: Author

Figure 7.16: Presentation of vulnerability, hazard, and risk maps for the rivers Elbe and Rhine regarding the forest sector

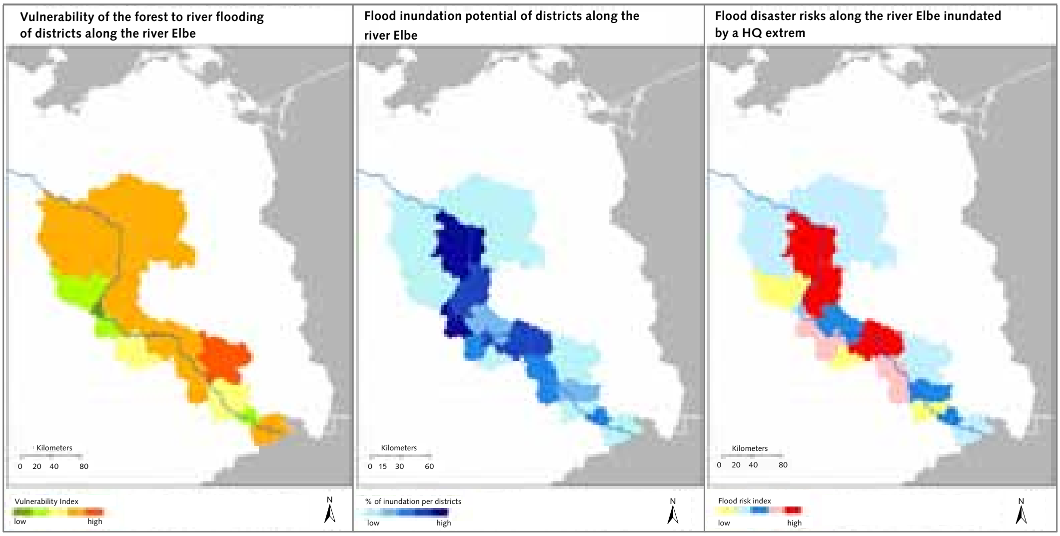


Vulnerability of the forest sector to river flooding of districts along the river Rhine

Flood inundation potential of districts along the river Rhine

Flood disaster risks along the river Rhine inundated by a HQ extrem

Vulnerability ranges between [-1,5, 2]. Five classes are built by using equal distances of the data range. Low values indicate low vulnerability, high indices represent high vulnerability in a district.	Percentage ranges from 0 to 70 %. Five classes were built by using equal distances as criterion for class building.	Flood risk index has been ranked in five classes. Natural breaks are used to build classes. A low index indicates low flood risk, a high index means high flood risk.



Vulnerability of the forest to river flooding of districts along the river Elbe

Flood inundation potential of districts along the river Elbe

Flood disaster risks along the river Elbe inundated by a HQ extrem

Vulnerability ranges between [-1,5, 2]. Five classes are built by using equal distances of the data range. Low values indicate low vulnerability, high indices high vulnerability in a district.	Percentage ranges from 0 to 45 %. Five classes were built by using equal distances as criterion for class building.	Flood risk index has been ranked in five classes. Natural breaks are used to build classes. A low index indicates low flood risk, a high index means high flood risk.

Source: Author

8. Discussion of concept and results

8.1 A deductive vulnerability assessment

Two different fields of research dealing with (1) vulnerability and (2) SES had to be linked in this study in order to meet the overall aim of assessing social-ecological vulnerability to flooding in the sectors of forest and agriculture. In chapter 3 the state of the art of theories and concepts were described in detail to enable identification of important elements and dynamics, and subsequently, to develop an appropriate conceptual basis for this study. In a further step, a modified version of the Turner model (Turner et al. 2003) was selected as a conceptual framework. The model considers vulnerability as embedded in a systemic framework and incorporates all important features that are crucial for a social-ecological vulnerability assessment. It successfully links both mentioned research disciplines in one conceptual framework and thus, from a theoretical perspective, provides an optimal basis for the research presented here. However, there needs to be a discussion on whether its components and dynamics reflect reality, and whether the framework also satisfies the demands of a practitioner-oriented approach. Consequently, this chapter addresses Research Questions 1 and 2 and discusses the validity and feasibility of the conceptual framework referring to the findings and results of this research.

8.1.1 Validity

The selected conceptual framework (see Figure 3.8) shows vulnerability as an emergent characteristic of the SES, and one that is determined by a variety of mutual interactions and feedback mechanisms between the social and ecological subsystems. Social and ecological influences from outside the place as well as social and ecological characteristics and processes at the place of analysis determine the overall vulnerability of a SES. The SES is understood as a complex adaptive system that exhibits not only all the characteristics of a complex system but also has the capacity to resist, cope, and adapt.

The validity of the proposed framework is tested by findings from expert interviews and a literature review (see Chapter 5). This chapter summarizes these findings and compares them to the elements and features of the conceptual framework.

First, the mutual interrelations and connectedness between social and ecological subsystems were clearly verified. For example, sustainable forest management contributes to forest health and vitality and thus influences ecosystem functions and services. Another example is the construction of flood protection measures (e.g. dykes), which has significant implications on land cover and ecological functions. Alternatively, changes in supporting services (e.g. soil formation or primary production) directly impact the provisioning or regulating of services. Accordingly, variations in one of the subsystems have direct or indirect consequences on the other subsystem.

Second, another key element of the framework deals with the dynamics and interactions that do not take place at one single scale but across various spatial scales and levels. For example, at federal state level the decision is made to establish a protection area. This has consequences for management and harvesting in a forested area and also impacts the condition of the forest ecosystem. A community might benefit from better hazard protection and higher recreational potential, or a household might suffer from less income due to reduced timber production. Hence, cross-scale interactions constantly take place in the forest and agricultural sectors and are an important aspect of complex adaptive systems.

Third, the capacities component encompasses three sub-components which could also be verified in the course of this research. In the social subsystem, coping with flooding starts at the moment when inundation threatens humans and their property. Farmers, for instance, evacuate their cattle, or a community tries to protect and safeguard dykes from overtopping or breaching. Adaptation usually starts after a flood event. In Germany, reinforcement of technical flood protection or changes in land use are common strategies for flood adaptation. In the ecological subsystem, adaptation is usually part of an evolutionary process such as the colonization of flood-resistant species. However, due to intensive use of ecosystems in Germany, ecosystems are often unable to adapt in the long run as they cannot develop undisturbed by human interventions. Ecosystem robustness is therefore an important feature that needs to be determined as it describes the capacity of the ecological subsystem to resist and withstand a perturbation (Holling 1973; Folke 2006; Gunderson 2000).

Fourth, the susceptibility component describes the actual state of the coupled SES, or the position of the SES in the stability landscape (Walker et al. 2004). Interviews with experts revealed that the current condition of a sector is mainly responsible for the degree to which it is damaged or affected by flooding. For instance, farmers who had already faced financial losses had more problems coping with an upcoming flood event. Another example is a forest ecosystem affected by serious wind damage or pests. The resulting poor condition reduces the forest's capacity to withstand a flood event.

Finally, the last important element in the framework which has to be verified, deals with the existence of external perturbations and stressors that might have a considerable influence on the dynamics in a SES. It was shown in the course of this research that hazards and stressors emerge not only from within a SES but also from the external environment (see Chapter 5). A flood event is only one example of how an external event can have strong implications on a SES, especially in an area not adapted to flooding. However, the boundary between external events and system-internal perturbations is sometimes hard to define. In this study an external stressor is not part of the common dynamics of a SES but is an exceptional event with strong implications for the natural dynamics.

So far, key elements, structures, and underlying theoretical concepts could easily be verified and reconstructed. However, some analytical constraints still exist which cannot be ignored:

- The analytical differentiation between the components of susceptibility and capacities is not absolutely clear. The vulnerability component capacities encompasses the capacities of a SES to bounce back, cope with, and adapt to hazardous events. These properties depend on the condition of a system, which is represented by the susceptibility component in the Turner framework. The findings showed that, for instance, healthy and vital ecosystems exhibit high ecosystem robustness; or economically advantaged regions have stronger capacities to cope with flood events. Thus, both components are strongly interrelated.

- Another important aspect which is not clearly solved in the model is the exposure component. The vulnerability research community has not agreed upon a common understanding of this component yet. Numerous scholars see exposure as closely related to the hazard component while others understand exposure as a hazard-independent component of vulnerability. Visually, the conceptual model places exposure within the vulnerability framework, but does not provide clear information on the true nature of the component. However, this creates the opportunity to implement the framework considering the characteristics and demands of the respective approach. In this research, exposure was treated as a hazard-independent component due to the sub-national scale at which the approach was conducted.

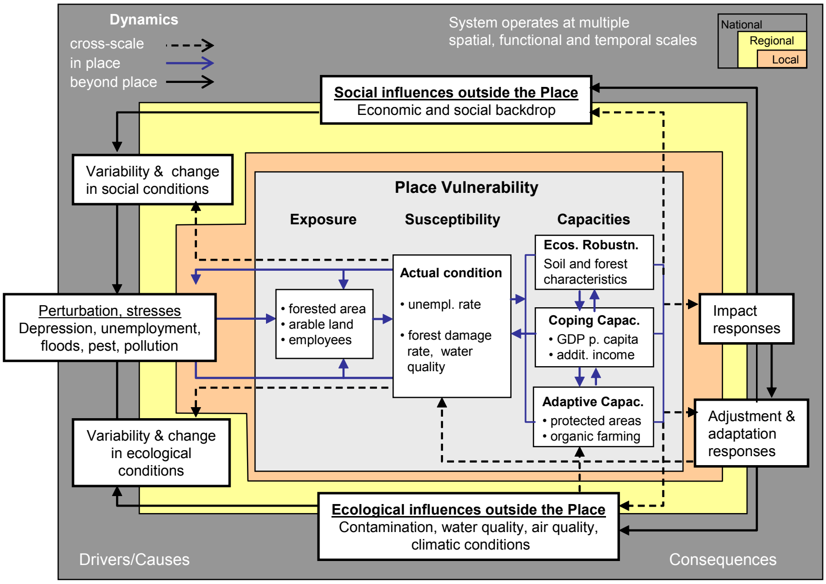
- Finally, the framework does not define the concept of risk, which necessitates the identification of an additional definition. By selecting a widely used definition in risk and hazard research (see Equation 1) the gap could be filled.

8.1.2 Feasibility

The conceptual framework integrates a large variety of elements and dynamics. Therefore, the operationalization turned out to be a challenging task. In this study, indicators were used to implement the framework and to assess vulnerability. Indicators have a long tradition as tools for assessing trends and conditions for policymakers and stakeholders. As already discussed in chapter 5, indicators also have some drawbacks; however, considering the approach which operates at regional level and which seeks to assist practitioners in their decision-making, indicators are considered as an appropriate tool. Figure 8.1 demonstrates how the different elements are interpreted and represented by a set of example indicators.

Altogether, the conceptual framework could be operationalized by means of indicators. However, some problems emerged during the implementation phase: the approach presented in this research is limited in its capacity to truly reflect dynamics and interlinkages between the single components and elements. To create a dynamic temporal and spatial vulnerability assessment, the availability of data at multiple scales with high temporal resolution is necessary. Usually, indicators (or the underlying data) are limited in their spatial and temporal availability and can thus hardly cover complex processes. Currently, scenarios can only be calculated assuming certain conditions. For example, in a multi-temporal approach which assesses vulnerability on monthly basis, the condition of a SES varies significantly, producing changes in the overall social-ecological vulnerability.

Figure 8.1: Conceptual Framework with some example indicators



Source: Author

The growing season, for example, is responsible for naturally changing conditions in the ecological subsystem over the course of the year. Growing season and crop season are tightly related. A flood striking just before planting may have limited impact, while flooding just after planting might produce substantial economic loss (lost seeds). Moreover, the conceptual framework aims to capture not only temporal and spatial but also functional dynamics. All components and processes are strongly interlinked and are coupled with feedback systems. Vulnerability is constantly changing because of variations in the SES. Only a highly sophisticated interactive calculation model and a deep understanding of all processes enables all these interactions and feedbacks to be captured.

In conclusion, despite some limitations, indicators facilitate the development of an understandable, reproducible approach which is transparent and feasible not only for scientists but also for practitioners. Nevertheless, the implementation of the assessment can be improved with regard to temporal and spatial dynamics. Due to a shortage of time and financial resources this could not be achieved in this study.

Altogether, the deductive approach proved to be an optimal solution to assess and map vulnerability. Since the concept of vulnerability emerged from social science and thus is mainly based on theories and concepts, it is only a logical consequence to base the assessment on a sound conceptual framework. The framework helps to (1) structure work, (2) identify essential elements, and (3) develop indicators. Moreover, it can be evaluated and verified with the results of the study.

8.2 The complexity of scales

Although a decade ago the matter of scale in SES and vulnerability assessments was still being debated, this issue has apparently been settled (see Chapter 3). Today, the discussion has shifted from the recognition to the conceptualization and implementation of multi- and cross-scale approaches.

In this research, the major challenge was to combine a finite unit of analysis (here: district) with an open SES represented by the sectors of forest and agriculture, and additionally to measure a phenomenon which changes across scales. Therefore, the selection of districts as the unit of analysis followed a thorough analysis of data availability, characteristics of both sectors, and demands of practitioners (see Chapter 3). The impact analysis revealed the dimension of cross-scale dynamics and interlinkages (see Chapter 5). Acknowledging the high complexity of cross-scale dynamics and the constraints in data availability, this research cannot claim to have integrated all existing interlinkages. The scope, complexity, and existing uncertainties around this issue make it impossible for any perspective, discipline, or approach to monopolize the answers and solutions. However, the first step towards a cross-scale approach has been made by including indicators from federal state to household level. Thus GDP per capita of federal state as well as income of households were used to describe forces and influences that shape coping capacities at district level. Furthermore, information on crown defoliation of forests at federal state level was used to characterize the overall condition of forest ecosystems in a region.

This study showed that it is possible to synthesize administrative units with closed, steady boundaries and the intangible boundaries of an open SES using a simple indicator-based approach. The technical mismatch of scales was corrected by up- and downscaling of data to district level using different methods. Unfortunately, a loss of information could not be avoided. However, this fact was taken into account by the use of weights during the aggregation procedure.

Wilbanks (2006) claimed to “include both top-down and bottom-up interactions, keeping its approaches consistent with its understandings of its subject” (Wilbanks 2006: 33). He underlined the following challenges that have to be met to bridge scales in social-ecological assessments: (1) to show that regional and local assessments can be at least as scientifically sound as global assessments, (2) to prove that qualitative deliberations and stakeholder participation can contribute to the science of social-ecological assessments, and (3) to develop more effective approaches for facilitating open mutual interaction between experts, institutions, and interests across scales.

This research faced all three above-mentioned challenges. First of all, a regional approach to assess vulnerability of the SES was carried out. The use of a sound conceptual framework and the subsequent evaluation of methods and results assure the soundness and reliability of the approach. The strength of the regional approach is that it clearly favours the integration of information stemming from various spatial levels. Being an intermediate level, the use of information from both upper and lower levels could be realized. Moreover, a regional approach generates an overview of trends, structures, and dynamics of vulnerability across Germany. However, some weaknesses also exist that cannot be denied: the reduction of information neglects many relationships and interactions and tends to simplify the processes and components that build vulnerability. Furthermore, for experts, the evaluation and analysis of processes and interactions at regional scale turned out to be very difficult. Still, the qualitative deliberations of the interviewed experts clearly facilitated the development of indicators. Although the science of SES and vulnerability is extremely complex and is still difficult to use by practitioners, their expertise contributed significantly to knowledge building and was thus indispensable. Since most experts were selected from organizations interested in the results of this study, the exchange of information facilitated the two-way interaction between experts and institutions.

8.3 Discussion of results and outputs

The overall aim of this research was achieved by mapping vulnerability to flooding for two sectors across districts in Germany. Indicators were identified and aggregated to a vulnerability index and subsequently visualized in a GIS. Applied methods and outcomes are discussed in this section.

8.3.1 Indicator selection

One major goal of this study was to answer Research Question 3, which deals with the development and identification of indicators for the vulnerability assessment. Following the methodological approach described in chapter 5, 13 indicators were selected to represent forest sector vulnerability, and 14 to assess the vulnerability of the agricultural sector. According to Moldan and Dahl (2007), the quality of indicators can be judged on five methodological dimensions: purpose and appropriateness in scale and accuracy, measurability, representation of the phenomenon concerned, reliability and feasibility, and communicability to the target audience. In this study the experience was that the selection of reliable and representative indicators is inevitably constrained by the availability and quality of the underlying data used to compose them. A perfect indicator hardly exists, since the design generally involves some methodological trade-offs between technical feasibility and systemic consistency. Limitations during the indicator development phase mainly emanated from the approach itself. Thus, many challenges had to be faced due to the fact that a regional approach transferable to the whole of Germany was to be developed. A procedure had to be established to meet these challenges. First, information on availability, type, and quality of data had to be collected. A large variety of data exists in Germany. However, due to the federal structure, data quality and quantity is often inconsistent. Most federal states have their own rules, conditions, and methods of data collection. Therefore, a careful and time-consuming evaluation of data was necessary prior to its final selection. Finally, demands and preferences regarding data characteristics had to be defined. In this study the decision was made to use data sources which already provide nationwide consistent data. Hence, on the one hand, data does not need to be acquired from each federal state separately. On the other hand, the selection of indicators is restricted to a certain amount of data. A clash between the identified number of appropriate indicators and the number that can finally be mapped cannot be avoided. Therefore, some important vulnerability categories could not be considered. In particular, categories that build coping and adapting capacities had to be ignored in the approach. For example, the state of emergency relief or risk awareness in a district could not be covered due to the lack of Germany-wide information (see Chapter 6). Still, the development and integration of a considerable number of indicators was accomplished. In comparison, the regional vulnerability assessment conducted in the ESPON project (ESPON 2005b) uses four indicators to describe vulnerability to flooding at district level.

The database 'Statistic Regional' proved to be a valuable source of socio-economic, demographic, and environmental information at district level. Since it is also updated continuously, indicators can easily be reproduced on a regular basis with new data. Unfortunately, environmental data do not have a broad spatial coverage, and can lack information value. Therefore, other sources such as the European Soil Database and the CORINE 2000 data were added as data sources. Both data sets cover almost all European countries. However, the use of several data sets also necessitates the synthesis of different data units. In this study all data had to be scaled to district level, causing inaccuracies in the data set. Therefore, the integration of various data sources has to be considered carefully, since it has obvious implications on the approach.

In conclusion, the selection of indicators followed a procedure of consecutive work steps including the building of important vulnerability categories, identification of indicators, and evaluation of theoretical and practical validity and feasibility. Although the indicator selection was mainly dependent on the quantity and quality of existing data, a considerable number of indicators could be identified for both sectors. Thus, the conceptual framework could successfully be interpreted and operationalized by means of indicators.

8.3.2 Vulnerability and risk index

In this study, Research Question 4 aimed to map vulnerability throughout German districts. The use of a composite vulnerability indicator was selected as an appropriate method to map vulnerability. The composite indicator was calculated by aggregating the scores of normalized and weighted indicators. Nardo et al. (2005) proposed distinct techniques for the development of a vulnerability composite indicator. However, keeping in mind the demands of a practitioner-oriented approach and the scale of analysis, an understandable and transferable technique had to be identified. Thus, the selection of normalization and weighting methods was considered carefully, taking into account the advantages and disadvantages of each technique (see Chapter 7). A z-score standardization was applied on all indicators before they were weighted and aggregated with the 'weighted sums' technique.

The result of a quantitative vulnerability assessment is prone to the subjective decisions of the scholar or expert. This means the subsequent evaluation of the selected approach is even more important. In this research, an attempt was made to reduce subjective control of the vulnerability index as much as possible. Therefore, weights were not assigned to emphasize the relative importance of indicators, but only to recognize poor data quality or statistical limitations. Moreover, vulnerability ranks were assigned by the equal distance method to avoid any positive or negative discrimination of results. The use of GIS to map and visualize vulnerability across Germany proved to be an optimal tool to identify hotspots of vulnerability. Exposure, susceptibility, and capacities were also mapped. The vulnerability maps of both sectors reveal that districts in the 'new federal states' are more vulnerable than districts in other parts of Germany. Low capacities and high susceptibility in many districts in east Germany result in high vulnerability. This is certainly comprehensible considering the historic background and the resulting socio-economic condition (see Chapter 2). However, the result has to be treated with caution. As already discussed above, the components of susceptibility and capacities are coupled with each other. This means that the influence of the susceptibility component on the final vulnerability index is probably too high. The influence could, for instance, be reduced by assigning lower weights to the susceptibility component. However, this implies strong intervention in conceptual and operational decisions and thus has to be considered carefully.

The vulnerability assessment covers only one important aspect of disaster risk. Thus, the hazard component has to be incorporated into the calculations in order to assess disaster flood risk. Therefore, a flood hazard needs to be closely analysed and defined to capture risk completely. This is no easy task, since, for instance, flood intensity is composed of various characteristics such as flood duration, flood extent, water depth, flow velocity, etc. Moreover, a flood event is not restricted to pure inundation due to high water levels, but is accompanied by further hazards such as a high sedimentation load, debris, or even ice sheets during winter floods. A clear concept on how to consider and integrate all these multiple hazards and characteristics in a risk assessment does not exist yet. Their combination and integration is very complex and requires careful consideration. Moreover, data or information about them is often missing or can only be obtained for a specific place, not for a whole region.

Since the major focus of this research was on the development of a sound vulnerability assessment, only one hazard characteristic was selected to demonstrate the assessment of disaster risk along the two rivers Elbe and Rhine. The flood extent of an HQextreme was used as an example to characterize the hazard. At district level, the percentage of inundated land area is a stable characteristic which can easily be derived from flood maps. Water depths or flow velocity are highly variable across space and are more difficult to characterize at district level. The multiplication of hazard and vulnerability scores produced a map showing the flood disaster risk potential of districts along the Elbe and Rhine for the sectors of forest and agriculture. Since vulnerability is mapped for all districts in Germany, risk can be assessed for all river systems if enough hazard data is available. A valuable basis for a large-scale assessment and Germany-wide analysis was thus developed.

8.3.3 Evaluation of methods and results

Evaluation of the approach is an indispensable part of each vulnerability and risk assessment. Analytical shortcomings as well as technical inaccuracies produce many uncertainties in the final result. Therefore, indicator development and index building were thoroughly evaluated in this research.

Robustness tests revealed low susceptibility of the vulnerability index to different calculation models. The strong robustness can be explained by the characteristics of the indicators and the selected approach. For example, no extreme outliers exist in the data set. Therefore, the differences between the distinct normalization methods are almost negligible. The diverse weighting techniques did not produce any strong variability either, since (1) no significant correlations exist between the indicators which are, however, necessary for the PCA, and (2) only a few weights (deviating from 1) were assigned to the single indicators. (3) Since there were quite a high number of indicators, compensability may also play a role. The highest volatility of vulnerability ranks can be observed between both aggregation methods. Again the underlying data structure is responsible for the degree of volatility. Hence, the vulnerability of the forest sector exhibits more changes of rank than the agricultural sector does (see Table 7.9).

A correlation analysis was conducted with the aim of detecting those indicators with the strongest influence on the vulnerability index. However, the coefficient of determination (r^2) revealed altogether very low correlations between indicators and vulnerability index, especially for the forest sector. Only unemployment rate and the exposure indicators show correlations with the vulnerability index. Since the data quality of these indicators is quite high due to their frequent and well-documented collection by the Federal Statistical Office, the reliability of the data is regarded as completely sufficient. Yet, as discussed in a previous paragraph it is recommended to reduce the influence of the susceptibility component on the vulnerability index in future research to avoid redundancies with the capacities component. This is particularly important because unemployment rate apparently has a significant influence on the final vulnerability index.

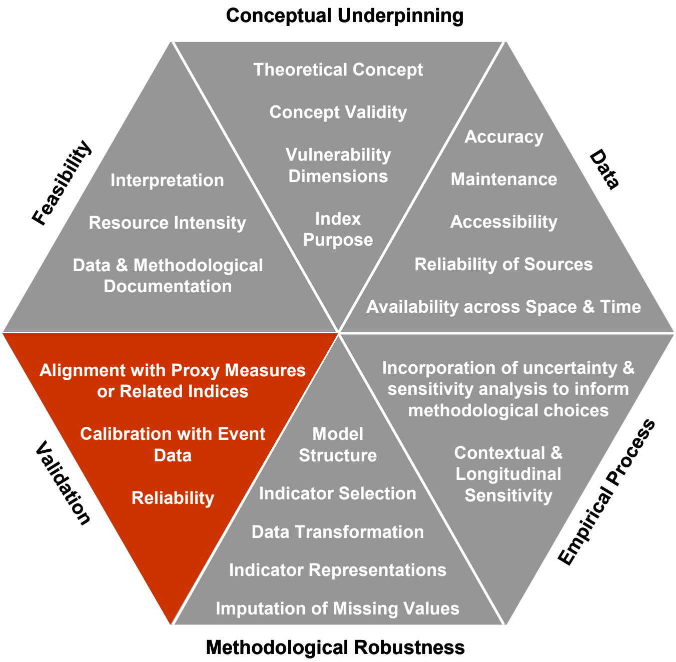
The sensitivity analysis was carried out with the indicators representing driving forces from levels other than districts, for example, GDP per capita of federal states. Lower weights were assigned to these indicators to take into account the reduced data quality due to scaling effects. Modifications of the indicator values or the complete exclusion of an indicator from the calculation model were used as methods to test the sensitivity of the vulnerability index to variations in the indicator set/model. The results revealed a very slight sensitivity of the final index. Volatility was thus negligibly low. This was not unexpected, since low weights intentionally reduce the influence of the selected indicators on the vulnerability index. Hence, the assignment of weights because of poor data quality proved to be a valuable tool to avoid high sensitivities.

A Monte Carlo analysis produced a range of uncertainty for each district. By means of this method it is possible to consider uncertainties regarding data quality, weights, and aggregation technique. The results present valuable information for users of the approach, since they allow conclusions to be drawn on the reliability and quality of the outcomes. Moreover, the uncertainty analysis proved the robustness of the approach, since the uncertainty range makes up only 12 % (15 %) of the actual vulnerability range of the forest sector (agricultural sector).

Statistical methods were applied to evaluate the quality and reliability of the index building. However, the robustness of the vulnerability index depends not only on its technical design but also on conceptual and epistemological uncertainties. Therefore, every major step ranging from concept building to indicator development was followed by an evaluation procedure taking qualitative and quantitative methods into account. Nevertheless, the question arises of whether a comprehensible evaluation procedure has been conducted covering all aspects of uncertainty (see Research Question 5).

Gall (2007) proposed a framework for index evaluation which spans conceptual, technical, methodological, and empirical aspects of the evaluation and construction of indices (see Figure 8.2). Indices are best evaluated ex-post or parallel to the construction process with regard to their conceptual foundation, quality of

Figure 8.2: Evaluation model



Source: Gall 2007

input data, empirical and methodological soundness, valid outputs, and overall feasibility to replicate the index.

By comparing the conducted evaluation procedure with the proposed framework it is clear that most aspects are indeed covered. (1) A conceptual framework was identified and further developed on the basis of the identified theoretical backdrop. (2) The internal soundness and validity of indicators was analysed and tested by means of statistical methods and empirical findings. (3) The index calculation model was tested for robustness by comparing it with different approaches. (4) Sensitivity and uncertainty analyses were carried out to inform about methodological choices. (5) The feasibility of the approach was strongly coupled with data availability and reliability. Indicators were only selected with regard to accessibility and replicability of underlying data. Transparent and understandable methods have been selected to foster the transferability and reproducibility of the vulnerability assessment. However, there is still one gap in the evaluation of the approach. Gall (2007) proposes a proper validation of the index, since vulnerability assessments build mainly on assumptions and subjective decisions. However, validation is not carried out in this research as no proxy variables were found to represent social-ecological vulnerability properly. Neither a regression analysis nor the information exchange with experts produced a meaningful result. Social-ecological vulnerability integrates two subsystems and captures various components and dynamics. Hence, it cannot easily be captured by one single proxy. The theoretical framework is therefore even more important. One possible way to validate the vulnerability assessment is through the comparison of historical and future flood events and their impacts. An analysis with historical event data has only limited validity though, since environmental and socio-economic conditions might have considerably changed over time and space. Nevertheless, several matches could already be detected by comparing the results of the risk maps with information and data gathered in expert interviews and from literature. For instance, the districts of Wittenberg and Stendal experienced enormous adverse impacts during the Elbe flood of 2002, resulting in serious economic and environmental consequences in the sectors of forest and agriculture (Geller et al. 2004; IKSE 2004). The district of Germersheim in South Rhineland-Palatinate was also affected severely during the Rhine flood in 1999 (see Chapter 6). High flood risk was calculated for this district, which confirms the reliability of the presented approach. Due to the temporal scope of this research no in-depth evaluation with historical events was carried out. Nevertheless, it is expected that future flood events will prove that the present vulnerability assessment ‘predicted’ the consequences. After validating this analysis through future floods, both the approach and the results could be adjusted and actualized.

8.4 Added value for disaster management

Enhancing disaster preparedness and reducing vulnerability are essential goals of disaster management in Germany (DKKV 2002). The results of this research are supposed to facilitate the efforts of national, federal state, and local disaster management authorities to deal with future flood events. The provision of an indicator-based vulnerability assessment supports the detection and monitoring of vulnerability patterns throughout Germany. The more is known about the state and the capacities in a region, the easier it is to think about precautionary measures and intervention tools. Figure 8.3 demonstrates the temporal development of actions during a disaster. From the reconstruction phase on, one has to start with the reduction of vulnerability. This can be, for instance, through the reconstruction of enhanced dykes or other technical protection measures; through the adaptation of land use to flood conditions in the preventive phase; or through the set-up of an early warning system in the preparation phase. Both reactive measures and preventive strategies have to be reinforced in disaster management (Merz 2006).

In order to contribute to this challenging task, this research followed a practitioner-oriented approach. Therefore, on the one hand, transparent and understandable methods were applied; on the other hand, guidance and documentation are provided on a public website which summarizes all the results of the DISFLOOD partnership[19].

Figure 8.3: Disaster cycle

Source: ClimChAlp 2008

---

[19] http://nadine.helmholtz-eos.de/intro_de.html

On the website, not only vulnerability maps are displayed but also the values of the underlying vulnerability components and sub-components. Thus, it will be possible to detect the sources of high vulnerability in a district.

In the 'Saale-Orla-Kreis', for example, high social stress combined with very low coping and adapting capacities result in significantly high vulnerability of the forest sector (see Chapter 7). Consequently, the state of the social subsystem needs to be considered by disaster managers, since the lack of capacities might have severe consequences during the intervention and recondition phase. In the district 'Leipziger Land' in Saxony both the social and the ecological subsystem are responsible for very high vulnerability of the agricultural sector to river flooding. Environmental stress is as high as social stress; consequently ecosystem robustness is quite low. Coping and adaptive capacities also lie under the overall average. This means that to reduce vulnerability, measures in both sub-systems must be considered.

Table 5.2 provides a list of categories which structure and describe each vulnerability sub-component. The categories, ranging from redundant networks to financial resources and risk awareness, may serve as guidelines for any disaster manager to test and improve prevalent vulnerability. Of course, some conditions cannot be changed rapidly, for example, the economic state of a district, but others such as land management strategies or the state of the emergency relief system can be changed in the short-term.

This research covers the assessment and mapping of social-ecological vulnerability. The results are complemented by studies on social vulnerability, hazard mapping, and flood event analysis carried out by other scholars within the DISFLOOD project. Together a comprehensive set of tools, methods, and maps was produced to facilitate and inform German disaster managers (see Fekete 2010: UNU-EHS Graduate Research Series vol. 4; Uhlemann (forthcoming); Zwenzner 2009).

8.5 Transferability of the approach

The last Research Question 6 deals with the transferability of the findings and results of the approach. Transferability across German districts was indeed guaranteed by the selection of methods in the approach. Transferability across national borders has to be analysed stepwise, since different individual work steps were addressed in the vulnerability assessment.

(1) The conceptual framework identified in this research can easily be applied in any place and sector worldwide. Some studies have already started to implement the Turner model (Ingram et al. 2006; Luers et al. 2003). The framework builds on theories and empirical findings of a universal nature and does not refer to a specific region or country. Furthermore, it was shown by this and other studies that different spatial levels can be addressed by the framework.

(2) In general, an indicator-based approach can easily be applied in any other country in the world. However, the methodology for the development and identification of vulnerability categories and indicators has to be adapted to

the circumstances in each country. The political situation, availability, and accessibility of data, socio-economic and environmental conditions, as well as administrative structures make it nearly impossible to completely transfer the developed methodology and indicators. The approach used in this research is of regional character and has emerged from the findings of expert interviews and literature referring to the consequences of flood events in Germany. It is recommended to start with an impact assessment to learn more about processes and dynamics in a country or region. From this point on, an indicator set can be determined taking the availability of data in the respective region/ country into account.

(3) The methods applied to build a composite vulnerability indicator were used in different scholarly works and can easily be transferred. However, the selection of normalization, weighting, and aggregation techniques should always be based on the structure of the underlying data and the purpose or use of the assessment.

(4) Evaluation should be carried out in every vulnerability assessment. Robustness tests, sensitivity, and uncertainty analyses were carried out in this study. The techniques used are easily transferable to other studies or approaches. Thus, transferability of the evaluation methods is definitely possible.

9. Conclusion and outlook

A large amount of information regarding social-ecological vulnerability to flooding has been collected for German districts. The great complexity of the topic and the lack of quantitative assessments of social-ecological vulnerability of the forest and agriculture sectors required the development of a methodology and the evaluation of methods and results. Consequently, the use of a deductive approach preceded by an analysis of theories and concepts and a post-evaluation of the findings of the research turned out to be a meaningful procedure.

One conclusion that can be drawn from the review of theoretical and conceptual frameworks and the experiences gained during this research is that it is not possible to determine one universal vulnerability concept or set of definitions that can be applied to every vulnerability assessment. It is more important to look into the characteristics and demands of the approach itself, and then to develop or to select a framework and working definitions which should be applied consistently in the study.

The conceptual framework used in this study provided a valuable basis for indicator development and composite indicator building. Despite its complexity it can be operationalized by means of indicators and thus fulfils the demands of being integrative, sophisticated, and yet feasible.

Capacities turned out to be one of the most determining components of vulnerability. Today, the concept of resilience, and in particular, of social-ecological resilience, is debated intensively in the research community. The framework manages to cover three different aspects of capacities, namely ecosystem robustness, coping, and adaptive capacity. These components go hand in hand with the characteristics of social-ecological resilience defined by Carpenter (2001) (see Chapter 3.4.3). It is strongly recommended that the dominant role of capacities for social-ecological vulnerability assessments should be acknowledged, and additionally, the coupling effects between the components of susceptibility and capacities should be analysed.

Indicators are valuable tools to quantify and map vulnerability. However, their selection is sensitive and complicated and requires the consideration of various selection criteria. The characteristics of the approach determine the indicator selection significantly. Place of analysis, scale, and target group have a great influence on the final selection. Moreover, data availability and accessibility play an important role. Therefore, substantial time and effort should be invested in the indicator selection in order to implement the concept. Involving experts and practitioners in the development phase can certainly be recommended. Although this study could not apply pure participatory methods due to the nationwide approach at regional level, sufficient knowledge was gained from interviews to build the indicator set.

The proposed indicator system is an efficient method of generating understandable and transferable information for decision makers or stakeholders in general. Indicators can be used as instruments to measure current disaster risk or to monitor the progress of risk reduction. The integration of environmental, socio-economic, and demographic indicators reveals the big picture of vulnerability to flooding.

The resulting vulnerability maps reflect very well the range of vulnerability across the districts of Germany. Thus, the composite vulnerability indicator fulfilled its purpose of detecting vulnerability patterns throughout the country. However, it is not enough to provide one overall vulnerability map. The underlying information about indicators or sub-components is also very valuable for stakeholders. Only with this information can they detect weaknesses and strengths and respond accordingly to them. Therefore, maps of all indicators as well as indicator scores are made available in this study and on the corresponding website.

This research aimed to provide a basis for future disaster risk analysis. The present approach has the great advantage that the results can be used for different purposes. Hence, a Germany-wide overview of vulnerability can be derived; but in addition, comparisons of vulnerabilities at the level of river basins or along river channels are possible.

Future research should look into analytical as well as technical aspects of the vulnerability assessment. Due to temporal and financial limitations these aspects could not be pursued in this research.

Analytically, the relationship between the susceptibility and capacity components must be further researched. Although this study tried to capture each component with indicators in order to fulfil the theoretical requirements of the conceptual framework, future research should consider whether a clear distinction and decomposition is meaningful or not. The question of whether the condition of a SES is not already captured by the capacity component has to be answered.

From a technical point of view, temporal dynamics still have to be integrated in the approach. However, temporal, spatial, and functional dynamics mainly rely on the amount and quality of data that are needed to build indicators and to actualize vulnerability maps. Yet, there is still a considerable potential to enhance the existing database. Moreover, capturing additional vulnerability categories is extremely desirable, since it could provide a more complete picture of vulnerability.

The indicators were ranked by means of statistical methods (e.g. equal distance). In future, indicators could be ranked using empirically proven thresholds as criteria for class building. This would definitively enhance the quality of vulnerability assessments, since not only relative but also absolute assessments would become possible.

Validation remains an open challenge for this study. More research must be done to work out whether some appropriate proxy measures are adequate or not. Another option is the review and analysis of consequences of past and future flood events. O'Brien et al. (2004a) and O'Brien et al. (2004b) conducted multi-scale vulnerability assessments in India and Norway to mutually validate the results. With a sufficient amount of data, this approach should be tested in Germany as well.

Vulnerability is the less-studied component of risk. Previous studies have focused on the hazard component instead. Along large rivers the hazard phenomena show considerable spatial and temporal variability – features which this study has also shown for social-ecological vulnerability.

Spatially (and temporally) distributed risk assessment would imply the need to integrate distributed information on all vulnerability components involved (Birkmann 2006b) and to consider simultaneously the respective hazard information of the corresponding referent (such as the district).

The present dissertation is a contribution towards this advanced risk assessment and governance.

List of figures

List of tables

Abbreviations and acronyms

AAG	Association of American Geographers
AGS	Official District Key
AHP	Analytical Hierarchy Process
ALFF	Office for Agriculture and Forestry Saxony-Anhalt
BBR	Federal Office for Building and Regional Planning
BFN	Federal Agency for Nature Conservation
BKG	Federal Agency for Cartography and Geodesy
BMELV	Federal Ministry of Food, Agriculture and Consumer Protection
CAS	Complex Adaptive Systems
CEC	Cation Exchange Capacity
CI	Composite Indicator
DFID	Department for International Development
DISFLOOD	Disaster Information System for Large-Scale Flood Events Using Earth Observation
DKKV	German Committee for Disaster Reduction
DLR	German Aerospace Centre
DLRG	German Safeguard Society
ESI	Environmental Sustainability Index
EU	European Union
EVI	Environmental Vulnerability Index
EWG	Expert Working Group
FAL	Federal Agricultural Research Centre
GGK	Water Quality Class
GDP	Gross Domestic Product
GIS	Geographical Information System
GVA	Gross Value Added
HDI	Human Development Index
IKSE	International Commission for the Protection of the Elbe

IKSR	International Commission for the Protection of the Rhine
IP	Interview Partner
IPCC	Intergovernmental Panel on Climate Change
LAWA	German Working Group on water issues of the Federal States and the Federal Government
LLFG	Agency for Agriculture, Forestry, and Gardening Saxony-Anhalt
LVA	Land Survey Office
MCA	Monte Varlo Analysis
MEA	Millenium Ecosystem Assessment
NABU	Nature and Biodiversity Conservation Union
NaDiNe	Natural Disaster Network
NRW	North-Rhine-Westphalia
OCC	Organic Carbon Content
PAR	Pressure-and-Release-Model
PCA	Principal Component Analysis
PVI	Prevalent Vulnerability Index
SD	Standard Deviation
SES	Social-Ecological System
SMU	Soil Mapping Unit
SOM	Soil Organic Matter
SOPAC	South Pacific Applied Geoscience Commission
STU	Soil Typological Unit
UBA	The Federal Environment Agency
UNDP	United Nations Development Programme
UN/ISDR	United Nations Strategy for Disaster Risk Reduction
UNU-EHS	United Nations University Institute for Environment and Human Security
WWF	World Wide Fund for Nature

References

Abraham, B.; D'Espaignet, E. T.; Stevenson, C. (1995): *Australian Health Trends*. Canberra, Australia, Australian Institute of Health and Welfare.

Adger, W. N. (2000): Social and ecological resilience: Are they related? In: *Progress in Human Geography.* vol. 24, pp. 347 – 364.

Adger, W. N. (2006): Vulnerability. In: *Global Environmental Change*. vol. 16, pp. 268 – 281.

Adger, W. N.; Brooks, N.; Bentham, G.; Agnew, M.; Eriksen, S. (2004): New Indicators for Vulnerability and Adaptive Capacity. In: Centre, T. (Ed.): *Technical Report 7*. Norwich, Tyndall Centre.

Adriaanse, A. (1994): *In Search of Balance: A Conceptual Framework for Sustainable Development Indicator*. London, Network seminar on sustainable development indicators.

Alexander, D. (1997): The study of natural disasters, 1977-1997: Some reflections on a changing field of knowledge. In: *Disasters*. vol. 21, pp. 283 – 304.

Allen, T. F. H.; Starr, T. B. (1982): *Hierarchy: Perspectives for Ecological Complexity*. Chicago, University of Chicago Press.

Anderies, J. M.; Janssen, M. A.; Ostrom, E. (2004): A framework to analyze the robustness of social-ecological systems from an institutional perspective. In: *Ecology and Society*.

Archer, K.; Gibbins, R.; Youngman, L. (1998): *Explorations. A navigator's guide to quantitative research in Canadian political science*. Toronto, ITP Nelson.

AAG (2003): *Global change and local places: estimating, understanding and reducing greenhouse gases*. Cambridge, Cambridge University Press.

ATEAM (2004a): *Final Report 2004*. <http://www.pik-potsdam.de/ateam/>, 5 May 2007.

ATEAM (2004b): *Final report 2004*. Section 5 and 6. In: Potsdam, P. (Ed.): PIK Potsdam.

Backhaus, K.; Erichson, B.; Plinke, W.; Weiber, R. (2006): *Multivariate Analysemethoden. Eine anwendungsorientierte Einführung*. Berlin, Heidelberg, Springer.

Bankoff, G.; Frerks, G.; Hilhorst, D. (Eds.) (2004): *Mapping Vulnerability. Disasters, Development and People*. London, Earthscan.

Barredo, J. I.; De Roo, A.; Lavalle, C. (2007): Flood risk mapping at European scale. In: *Water Science and Technology*. vol. 56, pp. 11 – 17.

Barrows, H. (1923): Geography as Human Ecology. In: *Annals of the Association of American Geographers*. vol. 13, pp. 1 – 14.

Bayerisches Landesamt für Umweltschutz (2004): *Umweltindikatoren Bayern*. Augsburg.

Beare, M.; Cabrera, M. L.; Hendrix, P. F.; Coleman, D. C. (1994): Aggregate-protected and unprotected pools of organic matter in conventional and no-tillage soils. In: *Soil Science Society of America Journal*. vol. 58, pp. 787 – 795.

Becker, E.; Jahn, T. (Eds.) (2006): *Soziale Ökologie. Grundzüge einer Wissenschaft von den gesellschaftlichen Naturverhältnissen*. Frankfurt, Campus Verlag.

Bennett, D.; Mcginnis, D. (2008): Coupled and complex: human-environment interaction in the greater Yellowstone ecosystem, USA. In: *Geoforum*. vol. 39, pp. 833 – 845.

Benson, C. (2004): Macro-economic concepts of vulnerability: dynamics, complexity and public policy. In: Bankoff, G.; Frerks, G.; Hilhorst, D. (Eds.): *Mapping Vulnerability: Disasters, Development and People*. London, Earthscan.

Berkes, F.; Colding, J.; Folke, C. (Eds.) (2003): *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge, Cambridge University Press.

Berkes, F.; Folke, C. (Eds.) (2000): *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge, Cambridge University Press.

Bernard, H. R. (2006): *Research Methods in Anthropology. Qualitative and Quantitative Approaches*. Oxford, Altamira Press.

BFN (2007): *Protected Areas*. Bonn.

Birkmann, J. (2006a): Indicators and Criteria for Measuring Vulnerability: Theoretical Bases and Requirements. In: Birkmann, J. (Ed.): *Measuring Vulnerability to Hazards of Natural Origin*. Tokyo, New York, UNU Press.

Birkmann, J. (Ed.) (2006b): *Measuring Vulnerability to Natural Hazards. Towards disaster resilient societies*. Tokyo, New York, Paris, UNU Press.

BKG (2006a): *ATKIS* – DLM250.

BKG (2006b): *ATKIS* – VG250.

Black, R. (1994): Livelihoods under stress: a case study of refugee vulnerability in Greece. In: *Journal of Refugee Studies*. vol. 7, pp. 360 – 377.

Blaikie, P.; Cannon, T.; Davis, I.; Wisner, B. (1994): At risk. *Natural Hazards, Peoples' Vulnerability and Disasters*. London – New York, Routledge.

BMELV (2006): *Bericht über den Zustand des Waldes* 2006. Berlin.

Bogardi, J. J.; Birkmann, J. (2004): Vulnerability Assessment: A First Step towards Sustainable Risk Reduction. In: Malzahn, D.; Plapp, T. (Eds.): *Proceedings for the International Conference*: *Disasters and Society – From Hazard Assessment to Risk Reduction*. Karlsruhe, Logos Verlag Berlin.

Bogardi, J.J. (2009): Last Lecture. *Paper presented during last lecture*. Bonn, 30 April 2009.

Bohle, H. (2001): Vulnerability and Criticality. Perspectives from social geography. In: *IHDP Update 2*.

Bollin, C.; Cárdenas, C.; Hahn, H.; Vatsa, K. S. (2003): Natural Disaster Network; Disaster Risk Management by Communities and Local Governments. *Inter-American Development Bank*. Washington D.C.

Boruff, B. J.; Emrich, C.; Cutter, S. L. (2005): Erosion hazard vulnerability of US coastal counties. In: *Journal of Coastal Research*. vol. 21, pp. 932 – 942.

Bratkovich, S.; Burban, L.; Katovich, S.; Locey, C.; Pokorny, J.; Wiest, R. (1993): *Flooding and its effect on trees*. <http://www.na.fs.fed.us/spfo/pubs/n_resource/flood/cover.htm>, 23 June 2007.

Briguglio, L. (2003): *The vulnerability index and small island developing states. A review of conceptual and methodological issues*. Paper prepared for the AIMS Regional Preparatory Meeting on the BPoA+10 Review. Praia, Cape Verde.

Broyer, S.; Savry, G. (2002): German leading indicators: Which one should be monitored? In: *CDC IXIS Capital Market Flash*. No. 2002 – 38.

Bühl, A. (2006): *SPSS 14. Einführung in die moderne Datenanalyse*. München, Pearson Studium.

Burton, I.; Kates, R. W.; White, G. F. (1993): *The Environment as Hazard*. New York, Guildford.

Cambridge Dictionary (2000): *Cambridge Dictionary of American English*. Landau, Cambridge University Press.

Cannon, T. (1993): A Hazard Need not a Disaster Make: Vulnerability and the Causes of 'Natural Disaster'. In: Merriman, P. A.; Browitt, C. W. (Eds.): *Natural Hazards.* London, Thomas Telford.

Cao, C.; Lam, N.-N. (1997): Understanding the Scale and Resolution Effects in Remote Sensing and GIS. In: Quattrochi, D. A.; Goodchild, M. F. (Eds.): *Scale in Remote Sensing and GIS*. Boca Raton, Lewis Publishers.

Cardona, O. D. (1999): Environmental Management and Disaster Prevention: Two Related Topics. In: Ingleton, J. (Ed.): *Natural Disaster Management.* London, Tudor Rose.

Cardona, O. D. (2001): *Estimación Holística del Riesgo Sísmico Utilizando Sistemas Dinámicos Complejos.* Barcelona, Universidad Politécnica de Cataluña, Barcelona.

Cardona, O. D. (2006): A System of Indicators for Disaster Risk Management in the Americas. In: Birkmann, J. (Ed.): *Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies.* Tokyo, New York, Paris, UNU Press.

Cardona, O. D. (2007): Indicators of Disaster Risk and Risk Management. *Program for Latin America and the Caribbean.* Washington D.C., Inter-American Development Bank.

Carpenter, S. R. (2008): *What is a social-ecological system?* <http://www.stockholmresilience.org/program/src/home/research/whatisresilience/whatisasocialecologicalsystem.4.25948b3d117af90ec9780007885.html>, 5 August 2007.

Carpenter, S. R.; Walker, B. H.; Anderies, J. M.; Abel, N. (2001): From metaphor to measurement: resilience of what to what? *In: Ecosystems*. vol. 4, pp. 765 – 781.

Cash, D. W.; Adger, W. N.; Berkes, F.; Garden, P.; Lebel, L.; Olsson, P.; Pritchard, L.; Young, O. (2006): Scale and cross-scale dynamics: governance and information in a multilevel world. In: *Ecology and Society*.

Cash, D. W.; Moser, S. C. (2000): Linking global and local scales: designing dynamic assessment and management processes. In: *Global Environmental Change*. vol. 10, pp. 109 – 120.

CEC (1985): *CEC – Soil map of the European Communities at 1:1,000,000*. Brussels, CEC-DGVI.

Chambers, R. (1989): Vulnerability, coping and policy. In: *IDS Bulletin*. vol. 20, pp. 1 – 7.

Chambers, R.; Conway, G. (1992): Sustainable rural livelihoods: practical concepts for the 21st century. *IDS Discussion Paper*. Brighton: Institute of Development Studies.

Chapin, F. S.; Lovecraft, A. S.; Zavaleta, E. S.; Nelson, J. C.; Robards, M. D.; Kofinas, G. P.; Trainor, S. F.; Peterson, G. D.; Huntington, H. P.; Naylor, R. L. (2006): Policy strategies to address sustainability of Alaskan boreal forests in response to a directionally changing climate. In: *PNAS*. vol. 103, pp. 16637 – 16643.

Christopherson, R. W. (1996): *Geosystems: An Introduction to Physical Geography. New Jersey*, Prentice Hall Inc.

Climchalp (2008): *Climate Change, Impacts and Adaptation Strategies in the Alpine Space. Common Strategic Paper.* <http://www.climchalp.org/>, 6 September 2007.

Colding, J.; Elmqvist, T.; Olsson, P. (2003): Living with Disturbance: Building Resilience in Social-Ecological Systems. In: Berkes, F.; Colding, J.; Folke, C. (Eds.): *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge, Cambridge University Press.

Cumming, G. S.; Collier, J. (2005): Change and Identity in Complex Systems. In: *Ecology and Society*.

Cutter, S. L. (1996): Vulnerability of environmental hazards. In: *Progress in Human Geography*. vol. 20, pp. 529 – 539.

Cutter, S. L.; Boruff, B. J.; Shirley, W. L. (2003): Social vulnerability to environmental hazards. In: *Social Science Quarterly*. vol 84, pp. 242 – 261.

Cutter, S. L.; Mitchell, J. T.; Scott, M. S. (2000): Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina. In: *Annals of the Association of American Geographers.* vol. 90, pp. 713 – 737.

Daily, G. C. (Ed.) (1997): *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington D.C., Island Press.

Damm, M.; Fekete, A.; Uhlemann, S.; Zwenzner, H. (2006): Development of a Disaster Information System for Large-Scale Flood Events Supported by Remote Sensing. In: Jüpner, R. (Ed.): *Strategien und Instrumente zur Verbesserung des vorbeugenden Hochwasserschutzes.* Magdeburg, Magdeburger Wasserwirtschaftliche Hefte.

DESTATIS (2008): *Economic data*. Federal Statistical Office.

DFID (1999): *Sustainable Livelihood Guidance Sheets.* <http://www.livelihoods.org/info/info_guidancesheets.html>, 21 March 2007.

Dister, E. (1983): Zur Hochwassertoleranz von Auwaldbäumen an lehmigen Standorten. In: *Verhandlungen der Gesellschaft für Ökologie.* vol. 10, pp. 325 – 366.

DKKV (2002): Extreme Naturereignisse – Folgen, Vorsorge, Werkzeuge. In: Tetzlaff, G.; Trautmann, T.; Radtke, K. S. (Eds.): *Zweites Forum Katastrophenvorsorge*. Leipzig.

DKKV (2003): *Hochwasservorsorge in Deutschland. Lernen aus der Katastrophe 2002 im Elbegebiet*. Bonn, DKKV.

Eakin, H.; Luers, A. L. (2006): Assessing the vulnerability of social-ecological systems. In: *Annual Review of Environment and Resources*. vol. 31, pp. 365 – 394.

ESPON (2005a): *Executive Summary. The Spatial Effects and Management of Natural and Technological Hazards in Europe – ESPON 1.3.1.* In: Schmidt-Thomé, P. (Ed.).

ESPON (2005b): *Final Report. The Spatial Effects and Management of Natural and Technological Hazards in Europe – ESPON 1.3.1.* <http://www.gsf.fi/projects/espon/>, 16 August 2007.

Esty, D. C.; Levy, M.; Srebotnjak, T.; De Sherbinin, A. (2005): *2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship.* New Haven, Yale Center for Environmental Law & Policy.

Federal and Provincial Statistical Offices (2006): *Statistik Regional*.

Fekete, A. et al. (2009): Scales as a challenge for vulnerability assessment. In: *Natural Hazards*. DOI 10.1007/s11069-009-9445-5.

Fekete, A. (2010): *Assessment of Social Vulnerability for River Floods in Germany.* Graduate Research Series vol. 4. UNU-EHS, Bonn.

Felgentreff, C.; Glade, T. (2008): *Naturrisiken und Sozialkatastrophen*. Heidelberg-Berlin, Springer.

Fenwick, E.; Claxton, K.; Sculpher, M. (2001): Representing uncertainty: the role of cost-effectiveness acceptability curves. In: *Health Economics*. vol. 10, pp. 779 – 787.

Fishman, G. S. (1995): *Monte Carlo: Concepts, Algorithms and Applications*. New York, Springer Verlag.

Folke, C. (2006): Resilience: The emergence of a perspective for social-ecological systems analyses. In: *Global Environmental Change*. vol. 16, pp. 253 – 267.

Folke, C.; Carpenter, S. R.; Walker, B. H.; Scheffer, M.; Elmqvist, T.; Gunderson, L.; Holling, C. S. (2004): Regime shifts, resilience and biodiversity in ecosystem management. In: *Annual Review in Ecology, Evolution and Systematics*. vol. 35, pp. 557 – 581.

Folke, C.; Pritschard, L.; Berkes, F.; Colding, J.; Svedin, U. (2007): The problem of fit between ecosystems and institutions: ten years later. In: *Ecology and Society*.

Frerks, G.; Bender, S. (2004): Conclusion: Vulnerability Analysis as a Means of Strengthening Policy Formulation and Policy Practice. In: Bankoff, G.; Frerks, G.; Hilhorst, D. (Eds.): *Mapping Vulnerability. Disaster, Development and People.* London Earthscan.

Frielinghaus, M.; Winnige, B. (2000): Maßstäbe bodenschonender landwirtschaftlicher Bodennutzung. Erarbeitung eines Bewertungs- und Entscheidungssystems zur Indikation der Wassererosion. *UBA-Texte*, 43-00.

Gall, M. (2007): I*ndices of Social Vulnerability to Natural Hazards: A Comparative Evaluation.* Department of Geography. Columbia, University of South Carolina.

Gallopín, G. (1994): Human dimensions of global change: linking the global and the local processes. In: *International Social Science Journal*. vol. 130, pp. 707 – 718.

Gallopín, G. (1997): Indicators and Their Use: Information for Decision-Making. In: Moldan, B.; Billharz, S. (Eds.): *Sustainability Indicators: Report of the project on indicators of sustainable development*. New York, John Wiley.

Gallopín, G. (2003): A systems approach to sustainability and sustainable development. *Medio Ambiente y Desarollo* 64. ECLAC, Sustainable Development and Human Settlements Division.

Gallopín, G. (2006): Linkages between vulnerability, resilience, and adaptive capacity. In: *Global Environmental Change*. vol. 16, pp. 293 – 303.

Geller, W.; Ockenfeld, K.; Böhme, M.; Knöchel, A. (Eds.) (2004): *Schadstoffbelastung nach dem Elbe-Hochwasser 2002. Endbericht des Ad-hoc-Verbundprojekts.* Magdeburg, UFZ Leipzig-Halle GmbH.

Gibson, C. C.; Ostrom, E.; Ahn, T. K. (2000): The concept of scale and the human dimensions of global change: a survey. In: *Ecological Economics*. vol. 32, pp. 217 – 239.

Giel, I. (2005): *Plan of the Rhine River in the 19th century*. <http://de.wikipedia.org/w/index.php?title=Bild:Rheinkorrekturplan.png&filetimestamp=20051212091528>, 21 July 2007.

Glenz, C.; Schlaepfer, R.; Iorgulescu, I.; Kienast, F. (2006): Flooding tolerance of central European tree and shrub species. In: *Forest Ecology and Management*. vol. 235, pp. 1 – 13.

Groh, A. P.; von Liechtenstein, H.; Lieser, K. (2007): The attractiveness of central eastern European countries for venture capital and private equity investors. *Working Paper IESE Business School*, University of Navarra, no. 677.

Gunderson, L. H. (2000): Ecological resilience – in theory and application. In: *Annual Review of Ecology and Systematics*. vol. 31, pp. 425 – 439.

Gunderson, L. H.; Holling, C. S. (Eds.) (2002): *Panarchy. Understanding Transformations in Human and Natural Systems*. Washington D.C., Island Press.

Hahn, H. (2003): Indicators and other instruments for local risk management for communities and local governments. *Document prepared as part of the documents related to the Project: Local risk management for communities and local governments*. GTZ.

Hair, J. F.; Anderson, R. E.; Tatham, R. L.; Black, W. C. (1995): *Multivariate data analysis with readings*. Englewood Cliffs, NJ, Prentice Hall.

Hák, T.; Moldan, B.; Dahl, A. L. (Eds.) (2007): *Sustainability Indicators.* Washington DC, Island Press.

Hammond, A.; Adrianse, A.; Rodenburg, E.; Bryant, D.; Woodward, R. (1995): *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development.* Washington DC, World Resources Institute.

Heiland, S.; Tischer, M.; Döring, T.; Pahl, T.; Jessel, B. (2003): *Indikatoren zur Zielkonkretisierung und Erfolgskontrolle im Rahmen der Lokalen Agenda 21*. Berlin, Umweltbundesamt.

Holland, J. (1995): *Hidden Order: How Adaptation Builds Complexity*. Reading, MA, Addison-Wesley.

Holling, C. S. (1973): Resilience and stability of ecological systems. In: *Annual Review of Ecology and Systematics*. vol. 4, pp. 1 – 23.

Holling, C. S. (2001): Understanding the complexity of economic, ecological, and social systems. In: *Ecosystems*. vol. 4, pp. 390 – 405.

IKSR (2001): *Rhine-Atlas.* International Commission for the Protection of the Rhine. <http://www.rheinatlas.de/>, 23 March 2007.

IKSE (2004): *Dokumentation des Hochwassers vom August 2002 im Einzugsgebiet der Elbe.* Magdeburg, Germany.

IKSE (2005): *Die Elbe und ihr Einzugsgebiet. Ein geographisch-hydrologischer und wasserwirtschaflicher Überblick*, Magdeburg.

Iles, J.; Gleason, M. (1994): *Understanding the effects of flooding on trees.* <http://www.extension.iastate.edu/Publications/SUL1.pdf>, 4 July 2007.

Ingram, J. C.; Franco, G.; Rumbaitis-Del Rio, C.; Khazai, B. (2006): Post-disaster recovery dilemmas: challenges in balancing short-term and long-term needs for vulnerability reduction. In: *Environmental Science and Policy.* vol. 9, pp. 607 – 613.

IPCC (2007): *Climate Change 2007: Impacts, adaptation and vulnerability.* Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press.

Jeffers, J. N. R. (1988): Statistical and Mathematical Approaches to Issues of Scales in Ecology. In: Rosswall, T.; Woodmansee, R. G.; Risser, P. G. (Eds.): *Scope 35: Scales and Global Change: Spatial and Temporal Variability in Biospheric and Geospheric Processes.* Chichester, John Wiley & Sons Inc.

Kaly, U.; Pratt, C.; Mitchell, J. (2004): The Environmental Vulnerability Index (EVI). *SOPAC Technical Report 384*.

Kaly, U.; Pratt, C.; Mitchell, J.; Howorth, R. (2003): The Demonstration. Environmental Vulnerability Index. *SOPAC Technical Report 356*.

Kapos, V.; Lysenko, I.; Lesslie, R. (2000): Assessing forest integrity and naturalness in relation to biodiversity. *Working Paper 54*. Rome, FAO.

Kasperson, J. X.; Kasperson, R. E.; Dow, K. (2001): Global Environmental Risk and Society. In: Kasperson, J. X.; Kasperson, R. E. (Eds.): *Global Environmental Risk.* New York, United Nations University Press.

Kasperson, J. X.; Kasperson, R. E.; Turner, B. L. (Eds.) (1995): *Regions at Risk. Comparisons of Threatened Environments*. UNU Press.

Kauffman, S. (1993): *The Origins of Order: Self-Organization and Selection in Evolution*. New York, Oxford University Press.

Kelly, P. M.; Adger, W. N. (2000): Theory and practice in assessing vulnerability to climate change and facilitating adaptation. In: *Climatic Change*. vol. 47, pp. 325 – 352.

Kelman, I. (2003): *Physical Flood Vulnerability of Residential Properties in Coastal, Eastern England.* Dissertation. Cambridge, University of Cambridge.

Kennel, M. (2006): Hochwasser ist ein natürliches Phänomen – Hochwasserschäden dagegen nicht. In: *Waldforschung aktuell.* vol. 11, pp. 35–36.

Kienberger, S. (2007): Assessing the vulnerability to natural hazards on the provincial/community level in Mozambique: The contribution of GIScience and remote sensing. *The 3rd International Symposium on Geo-information for Disaster Management, Joint CIG/ISPRS conference.* Toronto, Canada, 23 – 25 May 2007.

King, D.; Macgregor, C. (2000): Using social indicators to measure community vulnerability to natural hazards. In: *Australian Journal of Emergency Management*. vol. 15, pp. 52 – 57.

Korf, B. (2004): War, livelihoods and vulnerability. *In: Development and Change*. vol. 35, pp. 275 – 295.

Kotlarski, S.; Block, A.; Böhm, U.; Jacob, D.; Keuler, K.; Knoche, R.; Rechid, D.; Walter, A. (2005): Regional climate model simulations as input for hydrological applications: evaluation of uncertainties. In: *Advances in Geosciences*. vol. 5, pp. 119 – 125.

Kropp, J. P.; Block, A.; Reusswig, F.; Zickfeld, D.; Schellnhuber, H. J. (2006): Semi-quantitative assessment of regional climate vulnerability: the North-Rhine Westphalia study. In: *Climatic Change*. vol. 76, pp. 265 – 290.

Kumar, R. (1996): *Research Methodology.* Melbourne, Addison Wesley Longman Australia Pty Limited.

Kumpulainen, S. (2006): *Vulnerability Concepts in Hazard and Risk Assessment*. Geological Survey of Finland. Special Paper, 42, pp. 65 – 74.

Kupfer, J. A. (2006): National Assessment of forest fragmentation in the US. In: *Global Environmental Change.* vol. 16, pp. 73 – 82.

LAWA (2002): *Gewässergüteatlas der BRD – Biologische Gewässergütekarte 2000.* Hannover.

Lehmann, M. (2000): Reaktion von Gehölzen auf das Oderhochwasser im Jahre 1997. In: *Gesunde Pflanzen*. vol. 52, pp. 142 – 147.

Levin, S. A. (1998): Ecosystems and the biosphere as complex adaptive systems. In: *Ecosystems*. vol. 1, pp. 431 – 436.

Levin, S. A. (1999): *Fragile Dominion: Complexity and the Commons*. Reading, MA, Perseus Books.

LFU (2004): *Umweltindikatoren. Weiterentwicklung des Umweltindikatorensystems Bayer*n. Augsburg, Bayerisches Landesamt für Umweltschutz.

LFW (Ed.) (2003): *Hochwasserschutz im Wald*. LFW.

LFW (Ed.) (2004): *Vorbeugender Hochwasserschutz durch Wald und Forstwirtschaft in Bayern. Ergebnisse eines Demonstrationsvorhabens.* LFW.

Linndal, M. (2000): *Forest sector indicators. An approach for Central America*. Washington D.C., The World Bank.

Luers, A. L. (2005): The surface of vulnerability: An analytical framework for examining environmental change. In: *Global Environmental Change*. vol. 15, pp. 214 – 223.

Luers, A. L.; Lobella, D. B.; Sklard, L. S.; Addamsa, C. L.; Matsona, P. A. (2003): A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. In: *Global Environmental Change*. vol. 13, pp. 255 – 267.

Luhmann, N. (1984): *Soziale Systeme. Grundriss einer allgemeinen Theorie*. Frankfurt am Main, Suhrkamp.

Manson, S. M. (2001): Simplifying complexity: a review of complexity theory. In: *Geoforum*. vol. 32, pp. 405 – 414.

Marten, G. G. (2001): *Human Ecology. Basic Concepts for Sustainable Development*. London, Sterling, Earthscan.

Maskrey, A. (1989): *Disaster mitigation, a community based approach*. Oxford, Oxfam.

MEA (2003): *Ecosystems and Human Well-being.* A framework for Assessment, World Resources Institute. Washington D.C., Island Press.

Merriam-Webster (2003): Merriam-Webster's collegiate dictionary. Springfield.

Merz, B. (2006): *Hochwasserrisiken. Grenzen und Möglichkeiten zur Risikoabschätzung*. Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung.

Metzger, M. J.; Rounsevell, M. D. A.; Acosta-Michlik, L.; Leemans, R.; Schröter, D. (2006): The vulnerability of ecosystem services to land use change. In: *Agriculture, Ecosystems and Environment.* vol. 114, pp. 69 – 85.

Meuser, M.; Nagel, U. (2005): ExpertInneninterviews – vielfach erprobt, wenig bedacht. In: Bogner, A.; Littig, B.; Menz, W. (Eds.): *Das Experteninterview. Theorie, Methode, Anwendung*. Opladen, Verlag für Sozialwissenschaften.

Mitchem, J. D. (2004): P*lace vulnerability to tornadoes in the United States: a multi-scale assessment. Hazards & Vulnerability Research Institute*. Columbia, University of South Carolina.

Moldan, B.; Dahl, A. L. (2007): Challenges To Sustainability Indicators. In: Hák, T.; Moldan, B.; Dahl, A. L. (Eds.): *Sustainability Indicators. A Scientific Assessment.* Washington DC, Island Press.

Moore, D. R. J.; Warren-Hicks, W. H. (Eds.) (1998): *Uncertainty analysis in ecological risk assessment*. Pellston, USA, Society of Environmental Toxicology and Chemistry (SETAC).

Multihazard Mitigation Council (2002): *Parameters for an Independent Study to Assess the Future Benefits of Hazard Mitigation Activities.* Washington DC, National Institute of Building Science.

Munda, G. (2004): Social-multi-criteria evaluation: Methodological foundations and operational consequences. In: *European Journal of Operational Research*. vol. 158, pp. 662 – 677.

Nardo, M.; Saisana, M.; Saltelli, A.; Tarantola, S. (2005): *Tools for Composite Indicators Building*. Joint Research Centre. Institute for the Protection and Security of the Citizen. Econometrics and Statistical Support to Antifraud Unit. Ispra.

Nicoletti, G.; Scarpetta, S.; Boylaud, O. (2000): Summary indicators of product market regulation with an extension to employment protection legislation. OECD. *Economics department working papers* no. 226, ECO/WKP(99)18.

Niemeyer, M. (2002): Developing indicators for environmental policy: data-driven and theory-driven approaches examined by example. In: *Environmental Science & Policy*. vol. 5, pp. 91 – 103.

O'Brien, K.; Leichenko, R.; Kelkar, U.; Venema, H.; Aandahl, G.; Tompkins, H.; Javed, A.; Bhadwal, S.; Barg, S.; Nygaard, L.; West, J. (2004b): Mapping vulnerability to multiple stressors: climate change and globalization in India. In: *Global Environmental Change*. vol. 14, pp. 303 – 313.

O'Brien, K. L.; Sygna, L.; Haugen, J. E. (2004a): Resilient or vulnerable? A multiscale assessment of climate impacts and vulnerability in Norway. In: *Climatic Change*. vol. 64, pp. 193 – 225.

O'Neill, R. V.; Deangelis, D. L.; Waide, J. B.; Allen, T. F. H. (1986): *A Hierarchical Concept of Ecosystems*. Princeton, NJ. Princeton University Press.

O'Sullivan, D. (2004): Complexity science and human geography. In: *Transactions of the Institute of British Geographers*. vol. 29, pp. 282 – 295.

Oades, J. M.; Waters, A. G. (1991): Aggregate hierarchy in soils. In: *Australian Journal of Soil Research*. vol. 29, pp. 815 – 828.

OECD (2001): *Environmental Indicators for Agriculture. Volume 3 – Methods and Results*. Paris.

OECD (2006): *Main economic indicators*. Paris, OECD.

Oliver-Smith, A. (2004): Theorizing Vulnerability in a Globalized World: A Political Ecological Perspective. In: Bankoff, G.; Frerks, G.; Hilhorst, D. (Eds.): *Mapping Vulnerability. Disasters, Development and People*. London, Earthscan.

Openshaw, S. (1984): *The Modifiable Areal Unit Problem*. Norwich, Geo Books.

Pivot, J.-M.; Josien, E.; Martin, P. (2002): Farms adaptation to changes in flood risk: a management approach. In: *Journal of Hydrology*. vol. 267, pp. 12 – 25.

Pivot, J.-M.; Josien, E.; Testut, M.; Martin, P.; Gendreau, N. (2000): Flood hazard change and farmland vulnerability. *European Conference on Advances in Flood Research*.

Pryer, J. A. (2003): *Poverty and Vulnerability in Dhaka Slums. The Urban Livelihoods Study*. Dhaka, Ashgate Publishing, Ltd.

Quarantelli, E. L. (1992): *Urban vulnerability and technological hazards in developing societies*. Article 236. Newark, DE, University of Delaware. Disaster Research Center.

Ritsert, J. (1995): *Was ist Dialektik?* Frankfurt am Main.

Rusak, H. (2003): Fact sheet: forest fragmentation. In: Naturalists, F. O. O. (Ed.): *Woodlands at Risk.* Ontario.

Sächsisches Landesamt für Umwelt und Geologie (2004): *Ereignisanalyse – Hochwasser August 2002 in den Osterzgebirgsflüssen*. Dresden.

Scheffer, M.; Carpenter, S. R.; Foley, J.; Folke, C.; Walker, B. H. (2001): Catastrophic Shifts in Ecosystems. In: *Nature*. vol. 413, pp. 591 – 596.

Schellnhuber, H. J. (1998): Discourse: Earth System Analysis - The Scope of the Challenge. In: Schellnhuber, H. J.; Wenzel, V. (Eds.): *Earth System Analysis: Integrating Science for Sustainability.* Heidelberg, Springer.

Scherer-Lorenzen, M.; Körner, C.; Schulze, E.-D. (2005): Forest diversity and function. In: *Ecological Studies*. vol. 176.

Schmidt, W.; Zimmerling, B.; Nitzsche, O.; Zacharias, S. (2006): Möglichkeiten der Hochwasserminderung in der Landwirtschaft. In: *Dezentraler Hochwasserschutz*. vol. 17, pp. 33 – 44.

Schneiderbauer, S.; Ehrlich, D. (2004): *Risk, Hazard and People's Vulnerability to Natural Hazards. A Review of Definitions, Concepts and Data.* European Commission Joint Research Centre. EUR 21410 EN.

Schönleber, H.-F. (2006): Konservierende Bodenbearbeitung in einem sächsischen Ackerbaubetrieb als Beitrag zum dezentralen Hochwasserschutz. In: *Dezentraler Hochwasserschutz*. vol. 17, pp. 83 – 86.

Schüler, G. (2006): Identification of flood-generating forest areas and forestry measures for water retention. In: *For. Snow Landsc. Res*. vol. 80, pp. 99 – 114.

Schutkowski, H. (2006): *Human Ecology. Biocultural Adaptations in Human Communities*. Berlin, Heidelberg, Springer.

Schutzgemeinschaft Deutscher Wald (2001): *Auenwälder.* <http://www.sdw.de/wald/baum_infos/faltblatt-auen/imp-auen.htm>, 22 April 2007.

Simon, H. A. (1974): The Organization of Complex Systems. In: Pattee, H. H. (Ed.): *Hierarchy Theory: the Challenge of Complex Systems*. New York, Braziller.

Spekat, A.; Enke, W.; Kreienkamp, F. (2006): Neuentwicklung von regional hoch aufgelösten Wetterlagen für Deutschland und Bereitstellung regionaler Klimaszenarien mit dem Regionalisierungsmodell WETTREG 2005 auf der Basis von globalen Klimasimulationen mit ECHAM5/MPI – OM T63L31 2010 bis 2100 für die SRES-Scenarien B1, A1B und A2. *Projektbericht im Rahmen des F+E Vorhabens*.

Strotdrees, J. (2005): Landwirtschaftliche Nutzungskonzepte für Überschwemmungsgebiete im Kontext der Gewässerentwicklungsplanung Mittlere Leine. *NNA-Berichte*, 18, pp. 93 – 98.

Sullivan, C. A.; Meigh, J. R.; Mlote, S. (2002): Developing a water poverty index for Tanzania. *Conference paper for the Water Experts Conference*. Arusha.

Swanson, F. J.; Johnson, S. L.; Gregory, S. V.; Acker, S. A. (1998): Flood Disturbance in a Forested Mountain Landscape. Interactions of land use and floods. In: *Bioscience*. vol. 49, pp. 681 – 689.

The Heinz Center For Science Economics And The Environment (2002): *The State of the Nation's Ecosystems*. Cambridge, Cambridge University Press.

Thywissen, K. (2006): Components of Risk. A Comparative Glossary. *SOURCE No. 2/2006*. UNU-EHS, Bonn.

Timmermann, P. (1981): Vulnerability, resilience and the collapse of society. In: *Environmental Monograph*. Toronto, Institute for Environmental Studies, University of Toronto.

Turner, B. L.; Clark, W. C.; Kates, R. W.; Richards, J. F.; Mathews, J. T.; Meyer, W. B. (Eds.) (1990): *The earth as transformed by human action*. Cambridge, Cambridge University Press.

Turner, B. L.; Kasperson, R. E.; Matson, P. A.; Mccarthy, J. J.; Corell, R. W.; Christensen, L.; Eckley, N.; Kasperson, J. X.; Luers, A. L.; Martello, M. L.; Polsky, C.; Pulsipher, A.; Schiller, A. (2003a): A Framework for Vulnerability Analysis in Sustainability Science. *Proceedings of the National Academy of Sciences*, 100 8074-8079.

Turner, B. L.; Matson, P. A.; Mccarthy, J. J.; Corell, R. W.; Christensen, L.; Eckley, N.; Hovelsrud-Broda, G. K.; Kasperson, J. X.; Kasperson, R. E.; Luers, A.; Martello, M. L.; Mathiesen, S.; Naylor, R.; Polsky, C.; Pulsipher, A.; Schiller, A.; Selin, H.; Tyler, N. (2003b): Illustrating the Coupled Human-Environment System for Vulnerability Analysis: Three case studies. *Proceedings of the National Academy of Sciences of the United States of America*.

UBA (2004): *CORINE Land Cover*, DLR-DFG.

Uhlemann, S.; Thieken, A.; Merz, B. (forthcoming): *A Consistent Set of Trans-Basin Floods for Central Europe from 1951 – 2002.* Hydrology and Earth System Sciences.

UN/ISDR (2004): *Living with Risk, a Global Review of Disaster Reduction Initiatives.* Geneva, United Nations.

UN/ISDR (2005): Hyogo Framework for Action 2005 – 2015: Building the resilience of nations and communities to disasters. *World Conference of Disaster Reduction.* Kobe, World Conference of Disaster Reduction.

UNDP (2004): Reducing Disaster Risk: A Challenge for Development. A Global Report. In: Pelling, M.; Maskrey, A.; Ruiz, P.; Hall, L. (Eds.): New York, Bureau for Crisis Prevention and Recovery.

United Nations (2005): *Hyogo Framework for Action 2005 – 2015. Building the resilience of nations and communities to disasters.* <http://www.unisdr.org/eng/hfa/docs/Hyogo-framework-for-action-english.pdf>, 25 June 2007.

Van Der Ploeg, R. (2006): Schwerlast auf dem Acker. In: *Spektrum der Wissenschaft*. August 2006, pp. 80-88.

Van Lynden, G. W. J. (2000): *Guidelines for the assessment of soil degradation in Central and Eastern Europe*. Rome, FAO, ISRIC.

Villagrán de Léon, J. C. (2006): Vulnerability Assessment – the Sectoral Approach. In: Birkmann, J. (Ed.): *Measuring Vulnerability to Natural Hazards*. Tokyo, UNU Press.

Vincent, K. (2004): Creating an index of social vulnerability to climate change for Africa. *Working Paper 56.* Norwich, Tyndall Centre for Climate Change Research.

Von Bertalanffy, L. (1968): *General Systems Theory: Foundation, development, applications*. London, Allen Lane.

Walker, B. H.; Holling, C. S.; Carpenter, S. R.; Kinzig, A. P. (2004): Resilience, adaptability and transformability in social-ecological systems. In: *Ecology and Society.*

Watts, M. J.; Bohle, H. G. (1993): The space of vulnerability: the causal structure of hunger and famine. In: *Progress in Human Geography.* vol. 17, pp. 43 – 67.

Weichselgartner, J.; Deutsch, M. (2002): Die Bewertung der Verwundbarkeit als Hochwasserschutzkonzept – Aktuelle und historische Betrachtungen. In: *Hydrologie und Wasserbewirtschaftung.* vol. 46, pp. 102 – 110.

Wiener, N. (1948): *Cybernetics or control and communication in the animal and the machine.* Cambridge, MA, MIT Press.

Wilbanks, T. (2006): How Scale Matters: Some Concepts and Findings. In: Reid, W. V.; Berkes, F.; Wilbanks, T.; Capistrano, D. (Eds.): *Bridging scales and knowledge systems: Concepts and applications in ecosystem assessment.* Washington D.C., Island Press.

Wilbanks, T. J. (2002): Geographic scaling issues in integrated assessments of climate change. In: *Integrated Assessment*. vol. 3, pp. 100-114.

Wilbanks, T. J.; Kates, R. W. (1999): Global change in local places: how scale matters. In: *Climatic Change*. vol. 43, pp. 601 – 628.

Wilcke, D.; Akkermann, M.; Gieska, M.; Panebianco, S.; Bandermann, S.; Zimmerling, B. (2002): Innovativer Ansatz eines vorbeugenden Hochwasserschutzes durch dezentrale Maßnahmen im Bereich der Siedlungswasserwirtschaft sowie der Landwirtschaft im Einzugsgebiet der Lausitzer Neiße. *DBU Projekt Vorbeugender Hochwasserschutz im Einzugsgebiet der Lausitzer Neiße. Endbericht.*

Wischmeier, W. H.; Smith, D. D. (1978): Predicting rainfall erosion losses – guide for conservation planning. *In: Agriculture Handbook 537.* U.S. Department of Agriculture.

Wricke, B.; Tränckner, J.; Böhler, E. (2003): *Dokumentation von typischen Schäden und Beeinträchtigungen der Wasserversorgung durch Hochwasserereignisse, Ableitung von Handlungsempfehlungen.* Dresden, Technologiezentrum Wasser Karlsruhe.

Wu, J.; Li, H. (2006): Concepts of Scale and Scaling. In: Wu, J.; Jones, K. B.; Li, H.; Loucks, O. (Eds.): *Scaling and Uncertainty Analysis in Ecology.* Dordrecht, Springer.

WWF Deutschland (2007): *Hochwasser in Deutschland und Europa.* <http://www.wwf.de/fileadmin/fm-wwf/pdf_neu/Hochwasser_in_Deutschland_und_Europa.pdf>, 3 July 2007.

WWF European Policy Office (2004): Living with Floods: Achieving Ecologically Sustainable Flood Management in Europe. *Policy Briefing.* Brussels, Belgium, WWF.

Zwenzner, H.; Voigt, S. (2009): Improved estimation of flood parameters by combining space based SAR data with very high resolution digital elevation data. In: *Hydrology and Earth System Sciences*. vol. 13, pp. 381 – 394.

Mapping Social-Ecological Vulnerability to Flooding

A Sub-National Approach for Germany

by Marion Damm

In the last decades extreme river flooding has produced immense economical and ecological damages in Germany. Beside technical flood control measures there is a strong demand to enhance disaster preparedness and prevention. This requires the provision of sound methods and tools to support regional disaster management in Germany.

This PhD dissertation investigates the assessment of social-ecological vulnerability to flooding for the two sectors forest and agriculture. An approach is presented that allows mapping of vulnerability and risk at a regional level for all German river systems. In doing so, the major challenge is to produce usable outputs for practitioners. This study used indicators and Geographical Information Systems to operationalize complex theoretical frameworks. By applying a semi-quantitative approach a composite vulnerability indicator is developed and mapped for districts in Germany. A particular emphasis is also put on the evaluation of data and methods to detect and cope with uncertainties of the approach.

The research was conducted within the scope of the DISFLOOD project and was set up as a reaction to the political and scientific discussion on the development of applicable tools for the assessment and mapping of flood risk and vulnerability in Germany.

Marion Damm earned her PhD in Geography at the University of Bonn, Germany, while conducting her research within the structure of UNU-EHS.

UNU-EHS
UN Campus
Hermann-Ehlers-Str. 10
53113 Bonn, Germany

ISBN: 978-3-939923-46-6
ISSN: 2077-737X