

# Scales as a challenge for vulnerability assessment

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**Abstract** The aim of this paper is to introduce scale as a basic tool for improving the conceptual structure of vulnerability assessments. The terminology useful for vulnerability assessments and the current use of scale issues in theoretical vulnerability frameworks will be discussed briefly. Two case studies working on sub-national and on local level will demonstrate problems as well as benefits resulting from scale implications. Both assessments analyse vulnerability in context to river floods in Germany. In order to develop a spatial comparison and to integrate topics like environment and society, vulnerability assessments need to be aware of scale implications. The main point is that a scale debate on a broader spectrum than just in technical spatial terms is missing in vulnerability and risk conceptualisations so far. Vulnerability assessments and scale are highly intertwined, not only in technical application but also in conceptualisation, which needs more scientific development.

**Keywords** Vulnerability assessment · Scale · Hierarchy theory · Floods

## 1 Introduction

Scales are an important element in vulnerability assessments for different reasons. Firstly, place-based analysis seeks for detecting vulnerability at a certain locality (e.g. Cutter 1996, Turner et al. 2003) implying the selection of a certain unit of analysis. Secondly, systems and processes operate at a wide variety of spatial and temporal scales requiring a holistic overview of processes at multiple scales (Kasperson et al. 2001). Thirdly, cross-scale interaction exerts a crucial influence on outcomes at a given scale (MEA 2003). Thus, it is not surprising that intensive discussions on scale issues are permeating the vulnerability community. At the EWG IV in 2007 (Meeting of the Expert Working Group on social vulnerability held in Bonn in November 2007), it became obvious that different approaches

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are demanded, stressing the importance either to integrate cross-scale dynamics and to work at multiple scales, or to reduce complexity by rather focusing at one scale or level.

While multi-scale vulnerability assessments experience an increasing interest in vulnerability and resilience studies, there is a lack of awareness and documentation of scale terminology and conceptualisation. Some scientific disciplines and methodologies related to vulnerability assessments are rich in scale discussions. Examples are geography (Meentemeyer 1989), ecology (Levin 1992; Wiens 1989; Peterson and Parker 1998), global or climate change studies (Gibson et al. 2000), remote sensing and geographic information systems (GIS) (Quattrochi and Goodchild 1997). Some implications of scale are more technical or methodological problems, while the others are of more analytical or normative nature relating to the theoretical framework. Despite the abundance of challenges, the use of different scales in vulnerability assessments imply also chances for cross-scale and interdisciplinary comparability. Especially for the application but also for a deeper theoretical understanding, it is crucial to explore how and on which level or scale vulnerability is to be identified and how studies on different spatial levels can benefit from each other.

This paper aims at exploring how vulnerability assessments are practically applied on different spatial levels and which constraints or benefits of scale implications have to be faced. Therefore, scale effects in the conceptualisation as well as in the operationalisation phase of the assessment will be addressed. This paper wants to focus more on how theoretical and conceptual frameworks and scale implications of up- and down-scaling help to understand and conduct vulnerability assessments at different spatial levels. Finally, this paper aims at developing some recommendations that facilitate future vulnerability assessments with regard to the scale issue.

The paper is structured as follows: first, a brief summary on scale terminology is provided in order to present important terms and literature in this field of research as well as to introduce relevant notions of scale used in this paper. Following, a theoretical evaluation of theories and frameworks shows that to which extent scale concepts have already invaded vulnerability research. This chapter is supposed to give a short overview of the state of the art of concepts linking scale and vulnerability. The next chapter contains two case studies addressing vulnerability to flooding in Germany at local and sub-national level. After a short description of the respective study, scale implication in the conceptual, operational and end phase are delineated. The final discussion compares the results of the two case studies regarding scale implications and subsequently summarises and discusses the major findings of the previous chapters regarding scales. The paper concludes with some recommendations that are understood as a guideline for future multi-scale vulnerability assessments.

## 2 Scale terminology

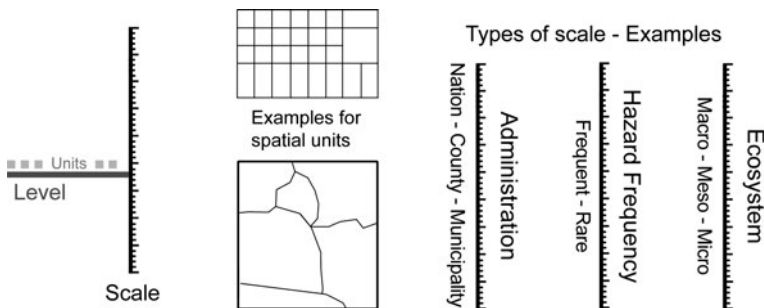
There is a confusing array of terminology when speaking about scale, e.g. cartographic scale, geographic scale, operational scale, relative scale or level of resolution (Jenerette and Wu 2000; Marston 2000) or measurement scales, e.g. nominal, ordinal, interval and ratio (Abella and Van Westen 2007). Following an expert workshop and after an extensive literature review, a set of working definitions has been proposed (Turner et al. 1989) that is found similarly in later literature. For example, the definition by Gibson et al. (2000) describes scale as “the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon.” The Millennium Ecosystem Assessment (MEA 2003) distinguishes the terms ‘scale of observation’ and ‘scale of the phenomenon’,

wherein the former is a construct of human measurement and the latter is a scale that each natural phenomenon characteristically has. Whether the latter actually exists or also is just a construct of perception remains open to discussion (e.g. Marston 2000). The observation scale can then be divided into three components (Turner et al. 1989; Gibson et al. 2000): extent (total area or time span of observation), resolution (the interval between observations, density or distribution) and grain (area or duration of single observations).

For a working definition, we find the existing terms very useful, however, some simplifications are necessary. This is prompted by our experience in integrating social and natural science terminology, but also due to comprehensibility to policy makers we want to address. First of all, we support distinguishing between scale and level (Fig. 1). The *scale* is the vertical axis along which any objects of interest are ranked, like on a ruler. *Level* is a fixed rank or horizontal layer on a scale. *Units* are, for example, homogeneous spatial entities like pixels, heterogeneous spatial entities like administrative boundaries (counties, postal code areas) or temporal units (Fig. 1). We prefer the term *unit* to ‘grain’, since we have the impression that grain refers more to pixels or raster units but not to administrative boundaries. Additionally, we find it more practical to use the term *research area* instead of ‘extent’. This is due to our observation to equate “the scale of an event” with magnitude, amplitude or extent in common language. The term *type of scale* distinguishes different spatial, temporal or other analytic scales (see Cash et al. 2006; Gibson et al. 2000).

### 3 Conceptualisation of scales in vulnerability research

An important issue permeating discussions of scale is the normative theory behind the structure of the elements of research. This is most apparent in the system theories debate, wherein different concepts concerning scales have been developed. Hierarchy theory, for instance, offers an approach to explore cross-scale interactions in coupled systems (Cash and Moser 2000). It facilitates the ordered examination of complex systems by disaggregating them into interacting processes and structures at different observational and spatial levels (Allen and Starr 1982; O’Neill 1988). Scale is by etymology and common use is closely related to hierarchical structuring. In fact, multi-scale comparisons, disaggregating techniques and top–down versus bottom–up discussions are hard to imagine without a conceptual notion related to hierarchy.



**Fig. 1** Explanation of the main working terminology used for scale, level and unit. (Alexander Fekete and Marion Damm; Types of scale adapted from Cash et al. 2006)

Hierarchy theory is one proponent of hierarchy and compartmentalisation theories, (Levin 1992) which is a major backbone for understanding scale implications. The term *hierarchy* has political connotation and especially some social or political science authors promote the agency perspective and bottom-up approaches in vulnerability assessments (Bohle 2007; Wisner et al. 2004). Hence, whether bottom-up or top-down, both analytical approaches draw instinctively from a hierarchical concept. Advantages and limitations of hierarchy theory have been discussed (Sarkar 1984) and there are also alternative approaches to hierarchy and scale like ‘flat hierarchy’ (Marston 2000; Leitner and Miller 2007) or an unranked parallel existence of systems (Luhmann 1984). The discussion about hierarchies and structures is rich in vulnerability related theories. For example, in complexity theory (Waldrop 1992) and ecology (Holling 1973) which have contributed to the research on complex adaptive systems (Holling et al. 2002; Peterson 2000). Within the Panarchy framework (Gunderson and Holling 2002) hierarchy is introduced as a nested set of adaptive cycles and the multiple connections between phases at one level and phases at another level are emphasised. Especially the perspective of human-environmental systems as coupled is a common basis for resilience and vulnerability research (Turner et al. 2003). While the interlinkages between spatial levels and the notion of integrating different types of scales (temporal, spatial) are laid down in the theories, in many of the conceptual vulnerability frameworks, the allocation of scales and levels is missing or is not explicitly described. This may be due to an implicit understanding of these frameworks to work on several spatial and temporal scales. Few approaches incorporate spatial-scale notions into their frameworks (Anderson and Woodrow 1998; Turner et al. 2003); structure-scale components along axes (Villagrán de León 2006) or include general temporal or logical progressions (Anderson and Woodrow 1998; Wisner et al. 2004; Birkmann 2006). Vulnerability is recently often described as a cross-scale issue, especially in climate change literature (Peterson 2000). This emphasises that vulnerable phenomena are nested at various levels and are interwoven in complex, sometimes nonlinear ways. This is not only a multiple spatial perspective, wherein each spatial level has to be treated separately. Moreover, cross-scale vulnerability assessment demands for the parallel observation of phenomena on various levels and types of scales. This holistic claim demands for more explicit cross-scale analyses but also for more explicit vulnerability frameworks.

#### 4 Two case studies on vulnerability to flooding in Germany

The following two vulnerability assessments are carried out at sub-national and local level. This enables the comparison of scale effects in conceptualisation, methods and results between both approaches.

##### 4.1 Study description of the sub-national approach

The flood-vulnerability assessment is conducted at sub-national level capturing the social and environmental dimension of vulnerability. Whereas the social vulnerability assessment addresses differences between social groups, the environmental study explores vulnerability of the two sectors forest and agriculture. The *outcomes* are visually easily comprehensible vulnerability maps displaying the internal predisposition of the subject of analysis to experience a disaster due to river floods at *county level*.

This study is one major package in the multi-disciplinary project ‘Disaster Information System for Large-Scale Flood Events Using Earth Observation’ (DISFLOOD, Damm et al.

2006). DISFLOOD will combine different methods like remote sensing, hydraulic hazard models and economic damage models with social and ecological vulnerability. The results are available on the Natural Disaster Network Web site NaDiNe ([http://nadine.helmholtz-eos.de/eos.de/projects/disflood/disflood\\_de.html](http://nadine.helmholtz-eos.de/eos.de/projects/disflood/disflood_de.html)). The prime *target groups* of NaDiNe are experts working on flood protection, regional planners and scientists. Moreover, the interactive maps will also be accessible to a certain degree by the public.

The methodology consists of a quantitative indicator assessment in combination with GIS functionality. The development of indicators is facilitated by impact analyses as well as by interviews with experts and affected people. For the construction of the indicators, demographic, economic and environmental characteristics are derived by federal statistical data (Destatis 2006). Furthermore, the indicators are organised after a selected vulnerability framework. In this approach vulnerability is defined by the three components exposure, sensitivity and capacities (Adger 2006). These components are contained in the conceptual frameworks applied: the SUST Model (Turner et al. 2003) and the BBC-framework (Birkmann 2006) guide the conceptual set-up and practical implementation of a place-based vulnerability assessment as conducted here. The authors use the following vulnerability definition:

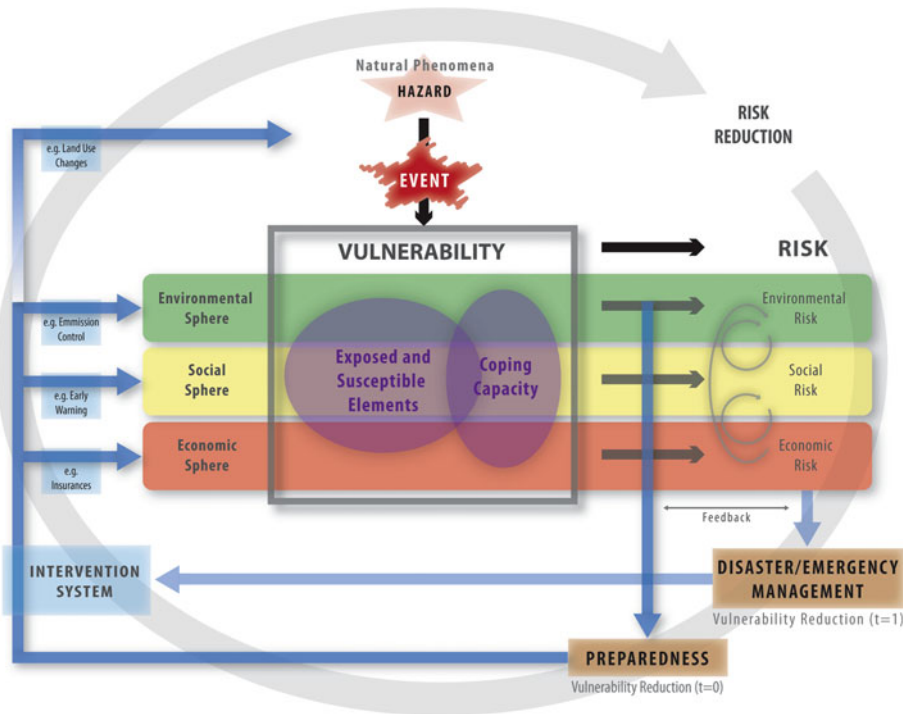
Vulnerability is the intrinsic and dynamic feature of an element at risk (community, region, state, infrastructure, environment etc.) that determines the expected damage/harm resulting from a given hazardous event and is often even affected by the harmful event itself. V. changes continuously overtime and is driven by physical, social, economic and environmental factors. (UNU-EHS, personal communication, 2004, as cited in Thywissen 2006: 34)

There exists a debate between different disciplines on the definition and concept of vulnerability, which is already extensively documented (Hewitt 1983; Cutter 1996; White et al. 2001; Brooks 2003; Few 2003; Adger 2006; Birkmann 2006). For our study, it was important to use a vulnerability concept, which can be applied by a place-based approach, capturing the spatial scale, but at the same time acknowledges the ‘dynamical features’ (see definition above) or temporal scale.

The conceptual BBC-framework (Fig. 2) can be applied on several spatial levels. Further, the BBC-framework aims at accounting for the linkages between the socio-economic spheres (who is vulnerable; e.g. social groups and institutions) and the physical–natural spheres (what is vulnerable, e.g. built environment, critical infrastructures, ecosystems and economic sectors). Thus, by addressing the three pillars of sustainable development, the framework clearly indicates the link between vulnerability assessment and sustainable development.

The framework emphasises the fact that vulnerability is defined through exposed and susceptible elements on the one hand, and the coping capacities of the affected entities on the other. This means that focusing on deficiencies is not enough.

Additionally, the BBC-framework incorporates the *temporal scale* of risk reduction and two temporal entry points of intervention. It shows that it is important to address the potential intervention tools that could help to reduce vulnerability in the social, economic and environmental spheres (Birkmann 2006) such as early warning. In this regard, the BBC conceptual framework promotes a problem-solving perspective. Furthermore, it stresses the importance of being proactive in reducing vulnerability before an event strikes the society, economy or environment ( $t = 0$ ) (Birkmann 2006). The assessment of options for introducing preventive measures ( $t = 0$ ), e.g. moving parts of a city out of its exposed



**Fig. 2** The BBC-framework (Layout: Stefan Kienberger after Birkmann 2006)

zone, do not aim only at saving lives but also at avoiding the disruption of sustainable livelihoods—the desired outcomes of a preventive intervention system ( $t = 0$ ).

## 4.2 Observations of scale implications at sub-national level

### 4.2.1 Conceptualisation phase

According to Gibson et al. (2000) and Wilbanks and Kates (1999), the spatial level of analysis needs to be congruent with the purpose of the assessment. Therefore, the selection of the level of observation and its units is a crucial step in vulnerability assessments, which needs to be considered thoroughly. In this case study, research area and level of observation were identified under the prerequisite to detect vulnerabilities in whole Germany at a sub-national level.

Firstly, we identified the overall conceptual frame as consisting of a relative space concept (Meentemeyer 1989) on the background on *system theory* (Von Bertalanffy 2006). The question was how to delineate and structure the vulnerable objects, the processes and their environments. We recognised that systems theory is underlying the more artificial separation of social and ecological systems, which were of interest. System theory helps to isolate certain elements of interest (e.g. humans) and their core interactions into a unit. This system or unit can assign boundaries to separate this phenomenon from its system environments. Within the relative space concept, our units of analysis and the research area are “defined by the spatial elements and processes under consideration” (Meentemeyer 1989).

*Hierarchy theory* provides the structure that enables the ranking of the system to discrete levels. We had to identify the existing vulnerability parameters and to figure out at which spatial level they can be observed for whole Germany. Taking a hierarchical model, we could either start with a bottom–up or a top–down approach. For the bottom–up approach we found it not feasible with our resources to capture enough variables with enough cases to extrapolate for whole Germany. Secondly, the variability of previous observations in literature were too great on variables like risk perception and human behaviour to allow propositions for whole Germany. We had to move to a higher level where spatial entities and temporal fluctuations are observable as patterns (Wiens 1989).

In order to combine multi-level information, we had to create an *interface* where vulnerability for whole Germany would become visible as a pattern. Therefore, we took an intermediate stance and viewed from the intermediate ‘level of observation’ simultaneously in both directions, up to the macro level and down to the micro level (Koestler 1967). On the micro level or ‘reductionist level’, all the phenomena take place that directly affect humans or ecosystems from a very local level; whereas on the macro level or ‘constraints level’, we found long term effects that govern people’s livelihoods or the state of ecosystems. Therefore, flood experience, income deficiencies and soil properties were as well as integrated in the approach as indicators like unemployment, ageing of population and large-scale pollutant dispersal from a macro level. (Table 1).

For our intermediate level of observation, we searched for suitable intermediate spatial units of analysis. Counties were chosen as *units of analysis* for several reasons: (a) counties are relatively homogeneous in size in comparison with municipalities and postal code areas, (b) disaster management as well as many other political processes are organised and supervised on the county level, (c) the objective to provide an overview of regional patterns with regard to large-scale flood events can be provided best at county level, (d) a sufficient number of variables is available by federal statistical data, (e) counties correspond to the designated European administrative unit NUTS3. This enables to transfer the approach to other European countries, and (f) counties are as administrative units readily understood by decision makers.

**Table 1** The hierarchy theory model modified for sub-national vulnerability of the environmental and social system

Level	Environmental system	Social system
Macro-level dynamics	Climate change Transboundary pollution	Ageing of the population National and global economic prosperity, globalisation
Level of observation (here: counties)	Fragmentation of landscape Protection status Land management	Fragility, marginalisation, dependency, welfare, economic prosperity as a profile of the average of all residents within a county
Micro-level components	Soil composition Vegetation type Hydrological conditions	Human behaviour Risk perception Social networks, skills, resources and physical fitness as a profile of a person



#### 4.2.2 Implementation phase

Scale implications during the implementation phase were tightly connected with data availability and methods used to collect those data. Constraints in availability and accessibility had to be faced due to the large research area of Germany. Especially *quantitative* data like statistical, spatial and environmental data available from national and sub-national authorities were found useful for mapping vulnerability across counties. However, data consistency needed also to be kept in mind. Every federal state applies different methods to calculate data sets. Therefore, beside the availability of data, data compatibility was a further constraining factor.

Due to a general lack of German-wide data, *qualitative* information was collected for the evaluation of indicators and the approach and for filling information gaps. Although it was difficult to identify experts with profound knowledge and overview of the interactions and processes on a regional scale, a field trip to Dresden during the Elbe flood 2006, telephone interviews with disaster managers of various municipalities as well as several interviews with environmental experts in Saxony-Anhalt enabled to draw a picture of stressors, intervention tools, flood awareness of the population and generally the status of flood protection in Germany.

For the *technical integration* of data from multiple sources and spatial levels, aggregation or disaggregation techniques had to be applied. Indicators like flood prewarning lead times, GDP per capita of federal states or crown defoliation was disaggregated to the spatial units of counties, whereas some spatially more precise information like land-use data, exposed infrastructure and historic flood occurrences had to be up-scaled to county level.

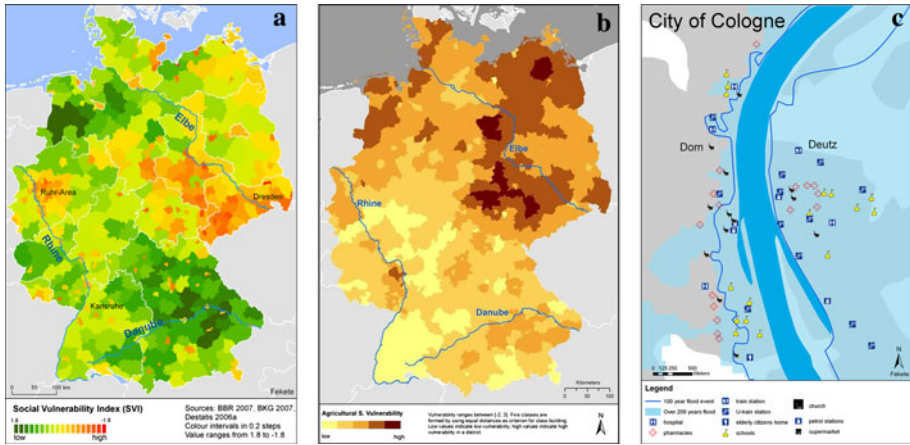
In order to account for the *spatial variation* of the area sizes of the counties in Germany, transformation of the variables were necessary. As vulnerability had to be mapped for the whole country of Germany, comparability of the results across counties had to be guaranteed. This required a transformation of some indicators from absolute values like GDP, unemployment and protected areas into relative values. This was accomplished by dividing the respective indicators by total population or total land area of the county.

Moreover, a weighting scheme was applied to build the final environmental vulnerability index. Data quality and correlations between variables instead of expert opinion methods (e.g. analytic hierarchy process) served as criteria to assign weights. This is due to the fact that a comparable approach for whole Germany is conducted, which makes a neutral and transferable weighting necessary. However, it was observed that the interviewed experts tended to refer to their specific local or regional knowledge and political background, which makes an objective rating difficult.

#### 4.2.3 Result phase

The result of the vulnerability assessments carried out at sub-national level is composite indices of vulnerability that can be mapped on county level using a GIS (Fig. 3a, b). The composite vulnerability indices are composed of single vulnerability indicators that are aggregated to normalisation, aggregation and weighting techniques, which were selected with regard to indicator properties and research design (Table 2, also: Fekete and Birkmann 2008; Fekete 2009; Damm 2008). For comparison of levels, the map of parts of the city of Cologne (Fig. 3c) shows that how much more details can be mapped by zooming in. Using point data, the locations of infrastructure within flood prone areas can be identified. This can be used for quantitative calculations of the number of important supply





**Fig. 3 a–c** The spatial level and research area of the sub-national (a, b) in comparison with a local vulnerability assessment (c)

infrastructure at risk, for example. But of course, just like on the sub-national level, this map (Fig. 3c) can also be used for qualitative analysis of, for example, planning of evacuation shelters. ‘Local level’ is in this respect a vague expression, just like ‘sub-national’, since it denotes a relative conception of research area. The units of research are more precise—counties or city boundaries.

Despite the conceptual and technical challenges, counties and the large research area have enormous advantages for *end-users*. The choice of county level meets the demands of policy makers and planners, who have to decide about administrative units. While grid units or arbitrary homogeneous boundaries might be better suited for calculation and scientific preciseness, the already established administrative boundaries allow better comprehensibility by the end-users (cf. Stephen and Downing 2001).

As another result of our methodological and conceptual approach, indicators and the counties as spatial entities can be *interlinked* to other data sources. Federal offices in Germany are working on the same administrative scale with the same data and apply similar indicators on socio-economic and environmental issues. The project partners of DISFLOOD can match their outputs to the county level as it would be possible to compare our results with other vulnerability assessments and other disciplines. This enables cross-validation with other hazard-impact patterns like economic damage. The major advantage of this approach is that the mapping is done for all counties in Germany. The full coverage offers cross-county comparisons in Germany, the detection of hot-spots, and facilitates the establishment of mitigation measures for risk reduction. Still, generalisation of data and information due to the regional approach make a thorough evaluation necessary. Opportunities for validation are given by comparison to the vulnerability assessments and other household surveys conducted on local level (see also Fekete 2009).

### 4.3 Study description of the local level approach

Local level also describes neighbourhoods or households. It is especially useful to carry out in-depth household surveys to collect important information about the vulnerability of the people. The study on vulnerability of communities exposed to floods at the local level in

**Table 2** Description of the vulnerability assessments of Fig. 3a–c

Social vulnerability on sub-national level (Fig. 3a)	Environmental vulnerability on sub-national level (Fig. 3b)	Infrastructure vulnerability on local level (Fig. 3c)
<p>Description: the map displays social vulnerability classes per county. Social vulnerability is highest where physical fragility, income deficiencies, population density related problems and lack of medical care prevail</p>	<p>Description: the presented map depicts vulnerability of the agricultural sector to river flooding at county level. Light colours represent low vulnerability whereas dark colours show highly vulnerable counties</p>	<p>Description: the exemplary map shows vulnerable infrastructure of a section of the city of Cologne. The blue line indicates the statistical 100 year flood event, the light blue area an extreme flood event exceeding a 200 year flood including dyke and protection wall failure</p>
<p>Composition: vulnerability indicators are created from demographic variables by grouping in a factor analysis. The preselection of the variables is guided by the conceptual components of vulnerability: susceptibility, capacities and exposure. A list of indicators can be found in “Appendix”</p>	<p>Composition: vulnerability is composed of the exposure, susceptibility and capacities. 15 indicators have been developed and grouped into the respective sub-categories. A list of indicators can be found in “Appendix”</p>	<p>Composition: this local analysis is just an example of the mapping of infrastructure and the according exposure calculation in combination with statistical flood scenarios. This information can be used for local planning of emergency shelter locations or the identification of potential failure of supply infrastructure</p>
<p>Method: indicator development by factor analysis; building ratios per county; equal intervals from 1,8 to –1,8 in 0,2 steps; equal weighting of the sub-indicators; simple sum</p>	<p>Method: the composite vulnerability indicator is built using the weighting sum technique. Indicators were normalised by the z-standardisation method. Five vulnerability classes were created by using equal intervals</p>	<p>Method: the location of infrastructure can be identified by point data like street addresses. This information can be used to calculate the number of infrastructure exposed</p>
<p>Data: census data (Destatis 2006; BBR 2007) and administrative boundaries (BKG 2007)</p>	<p>Data: Federal Statistical Office 2006, Federal Agency for Cartography and Geodesy 2007, CORINE 2000 (DLR-DFD 2007).</p>	<p>Data: land cover data of CORINE 2000 (DLR-DFD 2007), statistical flood area scenarios (IKSR 2001)</p>

urban areas encompasses different thematic clusters mainly, human vulnerability, environmental vulnerability and the vulnerability of critical infrastructure services (e.g. electricity). All assessments are based on the general conceptual BBC-framework (Fig. 2). One of the main challenges of this study is to identify appropriate characteristics and phenomena that represent susceptibility and coping capacity of elements exposed to floods at the local level using statistical data and new data gathered through a questionnaire based household survey. The combination of different data and survey methods allows also for integrating quantitative and qualitative characteristics of vulnerability. Some of the information can be mapped; however, other might serve as a profile of vulnerability for specific social groups. The results—mainly vulnerability indicators and criteria—can serve as an important tool within the framework of hazard and risk communication, such as early warning and preparedness. Moreover, they should also support the identification of hot-spots of vulnerability and can be used for risk reduction in urban and regional planning. The study encompasses different research methods and tools, such as remote sensing, questionnaire based surveys, expert interviews and literature research. The project receives financial support by the Federal Office of Civil Protection and Disaster Assistance (BBK)

and is undertaken in close collaboration with the cities Cologne and Dresden in Germany, both subject to flooding in the last decade. The major foci on the assessment of flood vulnerability can be summarised as follows: (a) Level—City, city districts and households; (b) Hazard—River flood scenarios and experience of past events; (c) Products Indicators, criteria, vulnerability maps and manuals. In the following sections scale implications will be discussed mainly using the example of social/human vulnerability.

#### 4.4 Observation of scale implications at local level

##### 4.4.1 Conceptualisation phase

The *choice of method* is influenced by the demand on detail and local context. The micro-level study aims at detecting the underlying causes and structures of vulnerability and focuses on details at the smallest statistical unit within a city. Apart from standard vulnerability parameter such as age, gender and people with disabilities, it also allows for capturing the ability of people to cope or adapt to flooding situations. Particularly the household questionnaire provides a flexible tool that allows the operationalisation of new aspects of vulnerability and coping capacity that are not represented in standard statistical data. Additionally, it can help to account for the specific spatial and development context of the region or municipality investigated. For example, the household survey for the city of Cologne included questions on knowledge concerning flood exposure, personal preparedness plans and the availability of flood insurance regarding coping capacity. In terms of intervention tools, the household survey explicitly tried to assess the knowledge about flood protection measures, and the evaluation of the flood protection activities undertaken by the city.

##### 4.4.2 Implementation phase

In our micro-level study, we aim to *integrate* data from different survey and data sources such as statistical data on the one hand and questionnaire based survey data on the other. Since not all the statistical data is available at the household level, we had to find an integrative level for all data. The integration is a trade-off between the detail-richness of the in-depth household survey and the aim of conducting an analysis for the whole research area of Cologne.

An important task for this integration is the “up-scaling” of indicators from the household level to the local or municipality level. This is undertaken using the information of some of the correlations found, for example, between the structure of a household and its evacuation capacity. Particularly, the household survey showed that households with children and elderly need significantly more time to leave the house than those households without children and elderly. This result at household level can be assumed as generally valid and projected to the whole city, using age and household structure data from the official local statistics. Limitations of up-scaling are met in personal opinions mentioned in the household survey, which cannot be generalised.

##### 4.4.3 Result phase

Overall, the local vulnerability assessment based on household interviews and statistical data shows that factors and vulnerability features, which closely correspond with certain

characteristics of the household or features of individuals, can be up-scaled by assuming that the same relation of behaviour or characteristics can also be found in groups, which have the same, for example, demographic structure. This up-scaling is not feasible for social vulnerability features, which are not significantly linked to the structure of a household or person. This is particularly true for some aspects such as power structures that can often solely be captured with difficulties and the up-scaling process is even more problematic.

Nevertheless, it is important to acknowledge that relations and characteristics of coping capacity or susceptibility can be investigated at a very fine resolution in a semiquantitative way. The study is ongoing, and its major products will be the development of guidelines regarding the measurement and assessment of vulnerability at the local level. These guidelines will encompass the documentation of the different methods and approaches used to measure vulnerability and coping capacity as well as recommendations to reduce vulnerability.

## 5 Discussion

### 5.1 Comparison of the sub-national and local study

In the previous sections, we have demonstrated two case studies on different spatial levels, sub-national and local. Implications arise by the choice of the respective spatial level for analysis that can be benefits or drawbacks. Data availability, the choice of the spatial level of analysis and the extent of the research area also had implications on the *selection of the methods* of the vulnerability assessment.

The sub-national vulnerability maps enable comparability of regions within Germany. Composite indicators are important tools for decision makers as they provide simplified and understandable information. They summarise information and provide insights in regional processes and patterns. The result is useful for regional planners, disaster managers and policy makers to define target areas of intervention. Sub-national assessments deliver valuable information about where and why certain areas are vulnerable to flooding. The composite index can be principally applied to any county in Germany. The county level is a compromise between the aim of generating an overview for the whole country and Germany-wide data availability. Due to the size of the units of analysis (counties), extreme event inundation areas are more suitable than small-scale floods. Scale implications are greatest in the conceptualisation, selection of data and methods, construction and presentation of the outputs.

In comparison, the local level case study demonstrates advantages in data mining and in capturing the roots of vulnerability. Some issues especially of coping capacities of local residents can only be captured at this spatial level. The local level also allows for the use of extensive household surveys and other participatory methods. Other locality-bound data like infrastructure or buildings can be mapped and identified whether they are within the hazard zones (Fig. 3a–c). Up-scaling is both a demand and challenge on this spatial level. Spatial generalisation effects and the levelling out of specific information like opinions are side effects of up-scaling.

Furthermore, the local study can serve to help validate the indicators of vulnerability developed in the sub-national approach of the first case study. Although one must always be cautious not to generalise from one locality like the city of Cologne to other counties or cities, both case studies can complement and help to validate each other. The BBC-framework can help to compare both studies by providing a common conceptual basis.

Table 3 summarises the differences and scale implications of local and sub-national and vulnerability assessments, which we detected in our case studies. For comparison, we also included typical characteristics of national/global vulnerability assessments (cf. Birkmann 2007). Many national level vulnerability indicators are constrained by data availability and explain vulnerability by only GDP or mortality rates, which is unsatisfying for sub-national comparisons (Birkmann 2007).

Knowing about the implications of vulnerability assessments on each level, it is interesting to investigate the general implications on the theoretical structure of vulnerability analysis. The following sections will compare our findings with known scale implications from literature, and synthesise which of the scale implications affect especially multi-level and multi-scale vulnerability analyses.

### 5.2 Multi-scale assessments: conceptual implications and technical problems

There is ample use of the terms *cross-scale* (Berkes 2006; Cash et al. 2006), *multi-scale* (Adger 2006; Gallopin 2006), *multi-level* (DFID—Department for International Development 2001) and multiple dimensions in the context of human-environmental research. However, scale, level and dimension are often used interchangeably and with unclear implications of the effect and the causal relations between different scales and levels. The reasons for confusion might be grounded in a lack of identifying, understanding and documenting scale implications on theoretical concept, methodology and results. The difference between cross-scale and multi-scale modelling is mentioned as multi-scale addressing scales without crossing them (Albrecht and Car 1999). Consequently, the need arises for theoretical and technical solutions to enable cross-scaling.

**Table 3** Pros and cons for vulnerability assessments on different levels in comparison to the other levels

Level	Pros	Cons
Local	<ul style="list-style-type: none"> <li>More detailed information can be included</li> <li>Complexity can be better captured</li> <li>Certain methods to collect data (e.g. participatory approach) can only be applied on local level</li> <li>Data availability for one place is mostly high</li> </ul>	<ul style="list-style-type: none"> <li>Transferability of the approach to another level or region implies loss of information</li> <li>Mapping of a whole river system is severely constrained by data availability</li> <li>Some data are very local specific and therefore complicated to compare with other cities or a region</li> </ul>
Sub-national	<ul style="list-style-type: none"> <li>Large-scale patterns and processes can be identified</li> <li>Intermediate level of analysis facilitates the incorporation of data from other spatial levels</li> <li>Data at regional level often available for whole country</li> <li>Less complex approaches are more applicable</li> </ul>	<ul style="list-style-type: none"> <li>Important vulnerability components can hardly be captured as e.g. perception or thresholds ⇒ tendency of simplification</li> <li>Dependency on available data as own collection is constrained</li> <li>Validation is difficult to carry out</li> <li>Variations in nature are difficult to capture</li> </ul>
National/global	<ul style="list-style-type: none"> <li>Meets the demand of allocating funds for parts of the world most affected by natural hazards or by social insecurity</li> </ul>	<ul style="list-style-type: none"> <li>Detection of root causes or holistic insights over patterns of vulnerability is limited</li> </ul>

Apart from the spatial-scale implications, the *temporal scale effects* remain a challenge for vulnerability assessments. For example, considering coupled systems (social-ecological processes) often requires the consideration of feedback loops between and within the systems (social or natural system) at multiple scales. The knowledge on how to capture these multi-scale interactions is still not very advanced, and the operationalisation is difficult, especially when dealing with two different phases of a crisis or disaster (see BBC-framework): (a) the phase before a disaster and (b) the situation during a disaster. Particularly, during and after disasters coping capacities at local level will be influenced heavily by interventions and interactions from the sub-national and national level. Thus, capturing the multi-scale interactions that might occur during a disaster is still a major problem.

We found a strong *coupling effect* of the human system with the natural hazard system due to overlapping temporal scales. For example, risk awareness and the memory time span of a previous flood is linked to flood frequency or duration (Fig. 4). In this case, we can observe that humans acquire a perception of the ‘normal’ or regular behaviour of the river. Even seasonal floods are not regarded as a hazard. As soon, however, as duration or frequency of the river floods are unexpected, a disaster can occur. This is an example of tipping points or critical thresholds in a coupled human-hazard system. These coupling effects are essential parts of multi-scale assessments and demand further investigation.

*Up- and down-scaling* are topics especially necessary for multi-level vulnerability assessments. It is hypothesised that the technical and the analytical dimensions are often not clearly dissected and often mixed together. Pragmatic application of spatial ‘container’ units and the use of proxies as indirect surrogates tend to obscure what is actually measured, when speaking about vulnerability. This invites critique by more qualitative approaches, which argue against a lack of context understanding, e.g. cultural differences. The counterargument of the more quantitative approaches is to provide at least a comparable and generalising data set. It is hypothesised that the up- and down-scaling demand of mostly applied quantitative approaches touches scale in its traditionally spatial meaning, while qualitative approaches tend to stress analytical scales.

There are, however, some *problems arising from up- or down-scaling* in multi- and cross-scale assessments we should be aware of. Before interlinking our results to other indices or other spatial levels, we must state some of the limitations due to our choice of units of analysis. These problems can be either related to the choice of spatial level for representation, the aggregation and resulting variation in results and false assumptions of generalising from one spatial level to the other. These problems are known as the ‘modifiable areal unit problem’ and ‘ecological fallacy’ (Openshaw 1984; Meentemeyer 1989; Cao and Lam 1997). They are especially important when dealing with census data on administrative units (Openshaw 1995). Fields like statistics and geocomputation have developed a range of tools to assess the uncertainty of spatial autocorrelation (Cao and Lam 1997).



**Fig. 4** Sketch for discussing coupling effects of river floods and human perception

*Generalising* from observations made on one level to another poses the scale problems of ecological correlation or fallacy (Robinson 1950; Cao and Lam 1997). It stereotypes individuals by the sum of characteristics of a whole group. Furthermore, precision is lost and local differences and context often crucial for vulnerability assessments are wiped out by aggregation (cf. O'Brien et al. 2004). Solutions for down-or up-scaling are well documented in statistics (Jeffers 1988) or GIS/Remote Sensing (Bian 1997; Peterson and Parker 1998; Wu and Li 2006). For data and methodological demands on different spatial levels, Wiens (1989) provides a useful table on the characteristics of various attributes at fine and broad scales. In order to ensure technical transferability of variables to other spatial levels, it is suggested to categorise variables into scale-dependent, scale-independent and non-scalable (MEA 2003).

Another important issue of making use of scales is the *validation by using other spatial levels*. Multi-level studies sometimes aim to validate a study on, for example, sub-national level with a study on local level (O'Brien et al. 2004). The same theoretical type of vulnerability assessment is targeted, however, with a different set of methods. The aim is to “ground truth” the larger-scale assessment. While it seems a natural step to combine micro- and macro-scale theories and methods, problems are long known in geography and general scientific theory (cf. Watson 1978). Still, one major challenge remains, that is the more holistic and multi-level one study becomes, the more interactions and complex relationships limit the predictability (Wilbanks and Kates 1999).

## 6 Recommendations

Resulting from the experiences of the presented vulnerability assessments of social and ecological issues related to river floods in Germany on two spatial levels, the following recommendations were identified.

- Scale implications (both benefits and drawbacks) need more attention and documentation within vulnerability studies.
- Guidelines for theoretical structure and application should be developed especially for integrative, coupled-systems analyses.
- Scale terminology should receive more attention, especially when multi-scale and cross-scale research is demanded.
- The choice of the appropriate spatial level driven mostly by data availability, policy demand, and aim of the concept should also be informed by theoretical considerations.
- The identification of the appropriate types of scale (spatial, temporal) and the type of nesting of phenomena (single-level, multi-level, cross-level) should be a prior step to conceptualisation.
- The development of a sound theoretical framework that includes an explicit structure of the scale should be given more weight as compared to technical scaling solutions.

## 7 Conclusion

In this paper, we have reviewed scale issues concerning vulnerability assessments and compared them to findings in two case studies regarding vulnerabilities in Germany on two spatial levels. The main purpose is to uncover conceptual flaws and neglected issues related to scale and its various types in relation to vulnerability assessments. It is argued that a



better structuring of concepts regarding scale, level or normative view is an important step before measuring and before any technical up or downscaling.

We demonstrated scale implications in our case studies in the normative structure and the application of theoretical frameworks, selection of the level and units of analysis, choice of methods, data availability, scaling, aggregation, target group use and the inter-linking with other studies or spatial levels of analysis. While time is an important scale, this study had to focus on spatial scale, its levels, units and interactions first. This spatial focus helped framing and improving our understanding of the analytical structure of our studies enormously. System theory and hierarchy theory were found especially helpful for conceptual structure.

While recent research in the field of vulnerability assessment stresses the holistic and interdisciplinary character, it is argued that a more transparent and thorough understanding of which vulnerability phenomena can be detected at which spatial level and scale might help enormously in the aggregation and combination of single aspects. This is of special importance in attempts to integrate qualitative and quantitative measurements, which have their own logic of underlying scales, structure and theory. This understanding would fundamentally support a better integration of physical processes and social models. Especially in the recently popularised multi-scale and cross-scale approaches, these scale implications are crucial. We observed a need for more terminological and conceptual clarity.

As an outlook, time spans are crucial to the social vulnerability towards river floods and will receive our future attention. For example, the coupled interdependencies of hazard parameters like flood frequency or duration, which influence the perception and impact of the hazard. Secondly, societal transformation like the ageing of the German society and the transformation by increasing in-migration from other countries are gradually reshaping the profile of German society and thus its social set of susceptibility. Another future field of investigation could be the creation of new vulnerability units or entities for measurement (for example, Kienberger 2007). Especially interesting would be spatial-temporal units. The most pressing research need at the moment, however, is the magnitude of changes imposed by climate change and other dynamics like population growth and transformation of society by ageing or migration. What if extreme events come more often and in greater magnitude? Which change in magnitude or frequency of a single variable will surprise us most? At which scale will we look at?

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## Appendix

See Tables 4 and 5.

**Table 4** List of indicators used for the social vulnerability assessment at county level (Fig. 3a)

Indicator (factor analysis)	Input variable	Vulnerability component
<i>Social vulnerability</i>		
Fragility	Age	Susceptibility/capacity
Socio-economic conditions	(Un)employment	Susceptibility/capacity
	Living space per person	Susceptibility/capacity
	Education	Susceptibility/capacity
Regional conditions	Population per settlement area	(Potential) exposure
	Apartment type	Susceptibility/capacity

**Table 5** List of indicators used for the environmental vulnerability assessment at county level (Fig. 3b)

Component	Sub-component	Indicator
<i>Environmental vulnerability of the agricultural sector</i>		
Exposure	Ecological system	% of farmland
	Social system	% of people employed in agricultural sector
Susceptibility	Human condition	Unemployment rate Federal State
		Unemployment rate district
	Ecological condition	Soil erosion potential
		Water quality index
Capacities	Ecosystem resilience	Potential contaminating sites
		Water retaining capacity
		Filter and buffer capacity
	Coping capacities	Dominating land use
		GDP per capita of Federal State
		GDP per capita of district
	Adaptive capacities	% of farmers with side income
		% of organic farms
		% of protected areas

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