Raumforsch Raumordn (2012) 70:293–308
DOI 10.1007/s13147-012-0172-0

WISSENSCHAFTLICHER BEITRAG

Tools for Resilience Building and Adaptive Spatial Governance

Challenges for Spatial and Urban Planning in Dealing with Vulnerability

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Received: 8 November 2011 / Accepted: 14 June 2012 / Published online: 20 July 2012

Abstract Climate change, resilience building and vulnerability reduction are emerging issues in spatial development and spatial planning in Germany, the European Union and globally. This paper introduces different concepts of and views on adaptation, vulnerability and resilience and outlines their implications for spatial planning in the context of a changing climate. On the basis of a conceptual discussion of key terms, the authors underscore the importance of assessing vulnerability as baseline information for the promotion of resilience and the enhancing of adaptation. The challenges of identifying and assessing vulnerability are illustrated through a case study of local flood vulnerability in Cologne with a specific focus on the vulnerability of different population groups as well as critical infrastructures. The respective key elements and phases of such assessments are identified. New challenges with regard to systemic risks are addressed and recommendations for improved linkages between spatial planning and civil protection formulated. The final part of the paper evaluates the upcoming challenges for adaptive planning in the context of climate change adaptation, for example regarding scenario development and its application.

Keywords Resilience · Vulnerability · Adaptation · Governance · Critical infrastructures

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Instrumente zur Förderung von Resilienz und adaptiver räumlicher Governance

Herausforderungen für Raum- und Stadtplanung im Umgang mit Vulnerabilität

Zusammenfassung Klimawandel, Resilienzbildung und Vulnerabilitätsminderung sind zunehmend wichtiger werdende Themen für Raumentwicklung und räumliche Planung in Deutschland, der Europäischen Union und global. Der Artikel bietet eine Einführung in ausgewählte Konzepte und Ansätze von Anpassung, Vulnerabilität und Resilienz, und skizziert ihre Implikationen für die räumliche Planung in einem sich wandelnden Klima. Auf der Basis dieser konzeptionellen Diskussion stellen die Autoren die Bedeutung von Vulnerabilitätsanalysen als grundlegende Information zur Förderung von Resilienz und Anpassung heraus. Die Herausforderungen der Identifizierung und der Analyse von Vulnerabilität werden anhand einer Fallstudie zur Vulnerabilität von Köln gegenüber Hochwasserereignissen verdeutlicht, wobei ein Schwerpunkt auf die Vulnerabilität unterschiedlicher Bevölkerungsgruppen sowie kritischer Infrastrukturen gelegt wird. In diesem Zusammenhang werden die verschiedenen Kernelemente und Phasen entsprechender Analysen herausgestellt. Dabei wird auch auf neue Herausforderungen im Hinblick auf systemische Risiken eingegangen sowie Empfehlungen für eine stärkere Verknüpfung von Raumplanung und Bevölkerungsschutz abgeleitet. Im abschließenden Teil des Artikels werden zukünftige Herausforderungen für eine anpassungsfähige Planung im Kontext der Anpassung an den Klimawandel skizziert und evaluiert, beispielsweise im Hinblick auf die Entwicklung von Szenarien und ihre Anwendung.

Schlüsselwörter Resilienz · Vulnerabilität · Anpassung · Governance · Kritische Infrastrukturen

1 Introduction

Five years after the World Conference on Disaster Reduction in Kobe, Japan, and in the light of the ongoing negotiations on a post-Kyoto protocol, vulnerability and adaptation to climate change are increasingly being discussed within the field of spatial and urban development in Germany. Also at the European and the global level spatial and urban planning are receiving more attention as important fields and tools for climate change adaptation, particularly regarding mega-urban, urban and peri-urban areas (see EC 2007a; EC 2009; IPCC 2012a).

At the global level, for example, the role of urban areas and spatial planning for climate change adaptation is being increasingly recognised in the Intergovernmental Panel on Climate Change (IPCC), which, in its upcoming fifth assessment report, will include an individual chapter on "Human Settlements, Infrastructure and Spatial Planning" (see IPCC 2009). An in-depth discussion of international experiences in spatial planning with mitigation and adaptation strategies can also be found in Davoudi/Crawford/Mehmood (2009). In addition, climate change adaptation is seen as a major issue in the light of territorial cohesion, where spatial planning plays an important role. In this context, the nexus between spatial planning and climate change adaptation has been stressed in the Green Paper (EC 2007a) and White Paper of the European Commission (EC 2009). Both documents underscore the importance of spatial planning for adaptive strategies at the regional level. The Green Paper stressed:"at the regional level, spatial planning is important for adapting to climate change, while at local level efforts should focus on practical land use and land management techniques and on raising awareness" (EC 2007b).

At the national level, the "German Adaptation Strategy" published by the Federal Government (Bundesregierung 2008) emphasised the fact that spatial planning has an important role to play in adaptation to climate change as it is, like civil protection, a cross cutting area. This strategy paper highlighted that spatial planning plays a pioneering role in developing guiding visions (*Leitbilder*) of an adaptive and resilient spatial structure, one that enhances societal capacities to deal with climate and non-climatic stressors through the strengthening of robustness and flexibility (Bundesregierung 2008: 42). Interestingly, both characteristics, robustness and flexibility, are seen as essential to enhancing spatial resilience (see e.g. Dosch/Porsche 2008; Birkmann/Fleischhauer 2009).

Additionally, a survey by the Expert Group on Climate Change and Spatial Planning of the Academy for Spatial Research and Planning (ARL) (conducted with regional planning agencies in Germany) revealed that particular challenges for regional planners in terms of climate change are linked to extreme events. These include floods, heat waves and storms, all of which will change as a result of the influence of climate change. Compared to this, the protection of infrastructures or the challenge of shaping a resource efficient settlement development are seen as important, but less pressing than ensuring protection against extreme weather events (see Overbeck/Sommerfeldt/Köhler et al. 2009).

More recently, the discussion on climate change adaptation has also been advanced through research projects and applied projects initiated in the context of the programmes: "Spatial development strategies for climate change"[1] and "Urban strategies on climate change"[2] as well as larger projects in the BMBF-programmes "klimazwei"(Research for climate protection and protection from climate impacts)[3], "KLIMZUG" (Climate change in regions)[4] and "KLIMAPAKT" (Adaptation to climate change through spatial planning), funded by the Leibniz Association.[5]

These projects deal with a broad range of topics, especially the identification of potential climate change impacts on the selected regions and cities as well as the discussion of response options. Such projects are an important trigger for a broader discussion on climate change adaptation in spatial development and planning at state, regional and local level. However, most of the results are still linked to specific thematic areas which focus on the individual context of the respective project based case study. Hence, it is still difficult to evaluate the net effect of these projects; the extent to which new guidelines might emerge to enhance the capacity of spatial planning to promote climate change adaptation and risk reduction. Most of the current results are linked heavily to specific regions and are based on the additional funding and expertise these projects offered. Thus, it remains to be seen how far these innovative projects can contribute to new standards for climate change adaptation through spatial planning for all regions and planning agencies in Germany. Nevertheless, these projects have already advanced the climate change discourse.

Referring to these discussions, two major phases of the discourse can be differentiated. Whereas the first phase of the climate change discourse was focused predominantly on

[1] Modellvorhaben der Raumentwicklung (MORO), Raumentwicklungsstrategien zum Klimawandel; see http://www.klimamoro.de (accessed 12.04.2012).

[2] Experimenteller Wohnungs- und Städtebau (ExWoSt), Urbane Strategien zum Klimawandel; see http://stadt-und-klimawandel.de (accessed 12.04.2012).

[3] See http://www.klimazwei.de (accessed 12.04.2012).

[4] See http://www.klimzug.de (accessed 12.04.2012).

[5] See http://www.klima-und-raum.org (accessed 12.04.2012).

physical climate change and its direct impacts on different regions and cities, the second phase puts more emphasis on the question as to how to adapt planning strategies and tools to better account for climate change adaptation. For example, topics such as "resilient spatial planning" and "climate proofing" or the enhancement of strategic environmental assessment are being discussed by researchers and practitioners (see e.g. Birkmann/Fleischhauer 2009; Greiving 2011: 26). However, some practitioners argue that spatial planning does not need new tools. Rather, the application of existing tools needs to be strengthened. Hence, there is no consensus on the degree to which new standards and further tools are needed to enhance the capacity of spatial planning to build resilience and promote climate change adaptation.

Against this background, the paper provides a detailed study of new tools and methods, such as vulnerability assessments for critical infrastructures, different city areas and people exposed to natural hazards, particularly floods. While on the one hand city areas and people can be affected by flooding due to direct exposure, there is also the possibility that citizens in flood prone areas can be highly affected by the indirect effects of floods, such as the shortfall or even break down of infrastructure services, such as electricity networks. To maintain the functioning of critical infrastructures in times of adverse events, these systems have to be planned accordingly. Based on the case study of the city of Cologne, Germany, the different direct and indirect effects of flooding are illustrated by focusing in particular on the vulnerability of people and critical infrastructures. In doing so, the authors emphasise that spatial planning needs to consider the various aspects of vulnerability, particularly exposure, susceptibility and societal response capacities.

In contrast to the notion that adaptation in spatial planning requires first and foremost the adjustment of physical structures, we argue that planning procedures, methods and information sources need to be enhanced in order to promote adaptive urban governance. Hence, the assessments presented highlight a paradigm shift from hazard identification (e.g. flood hazard maps) to the assessment of the variety of vulnerabilities as a starting point. Consequently, the paradigm shift and the methods presented are important pillars of adaptive spatial governance. In this context, the paper deals particularly with the following four key questions:

- How are core concepts—particularly adaptation, vulnerability and resilience—defined and conceptualized by different schools of thought?
- How can vulnerability, risk and adaptation be framed and operationalised for practical assessments at the local and provincial level of flood affected areas?
- Which indicators, criteria and data sources can be used to assess core components of vulnerability, particularly exposure, susceptibility and response capacities (e.g. coping capacities) at the local level in Germany?
- How can these assessments and methodologies serve as tools for adaptive spatial governance?

2 Revisiting: Adaptation, Vulnerability, and Resilience

Many planning strategies and formal planning documents still focus primarily on the physical changes brought about by climate change (e.g. changes in precipitation and temperature). It is, however, crucial to emphasise that risks due to climate change are a result of physical changes on the one hand, and socio-economic and spatial structures and development patterns on the other (IPCC 2012b). In this regard this paper stresses that risks and adaptation needs are socially constructed. This does not mean that climate change is not real or a physical phenomenon. However the risks linked to climate change and the requirement for spatial planning to deal with adaptation are determined by the vulnerability and resilience of the exposed system to climatic stress. If people or systems (e.g. infrastructure, land use and production systems) in a specific region are not vulnerable, there would be no need to consider adaptation. Many regions are, however, vulnerable to climate change and therefore the complexity of climate change risks and adaptation processes has to be considered if sustainable spatial development is to be achieved. Spatial planning is one of the cross cutting areas that can help to harmonise various sectoral adaptation strategies (e.g. agriculture versus water management). In this regard, adaptation strategies aim to reduce vulnerability and to increase resilience. Nevertheless, the terms adaptation, vulnerability and resilience are not precisely defined, but interpreted in different ways. For this reason they are revisited in the following section.

2.1 Different Views on Adaptation

Although spatial planning has a certain history in utilising complex terms as guiding principles and visions (e.g. "sustainable spatial development"), it is worth noting that "adaptation to climate change" is a contested term. In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change defined adaptation as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderate harm or exploits beneficial opportunities" (IPCC 2007: 869). Smith/Bhatti/Menzhulin et al. (1996: vii) extended upon this definition by adding that "adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system".

While the definitions shown above are not right or wrong, they tend to suggest that human systems mainly adapt through adjustments in direct response to actual or expected climatic stimuli. This is a rather mechanistic understanding of adaptation. In particular, the view that environmental change is a major pre-condition for respective adjustments is questionable. In reality adaptation processes are heavily influenced by perceptions, different cultural contexts and normative systems as well as governance processes. Thus a rather simple understanding of adaptation as a linear response to environmental change is inadequate, at least for complex human-environmental systems such as cities or regions.

At least two major schools of thought on adaptation to climate change can be differentiated. Smit and Wandel (2006: 283) distinguish between a natural science and a social science perspective and emphasise that “in natural science adaptation is often viewed as the development of genetic or behavioural characteristics which enable organisms or systems to cope with environmental changes in order to reproduce and survive”.In contrast, social science approaches: “examine adaptation often with regard to cultural practices allowing societies to survive in the light of climate induced changes. Within these approaches, behavioural and technological innovations are considered and discussed” (Smit/Wandel 2006: 283).

Overall, spatial planning strategies for climate change adaptation have to be sensitive to the different definitions and views actors have of adaptation and the potential consequences of using one of these as an entry point for the definition of tools and measures.

2.2 Vulnerability

In contrast to a purely hazard oriented risk management focus, academic discussions in recent decades have shown that (potential) damages due to extreme events do not solely depend on the hazard or climate stimuli as such (see Liverman 1990; Blaikie/Cannon/Davis et al. 1996; UNISDR 2004; Cannon 2006; Birkmann 2006a; UNISDR 2009). Rather vulnerabilities in society, its infrastructure and land use system play a key role, influencing the actual harm and damage, or damage potential. Consequently, vulnerability and risks are socially constructed. In a broader sense, vulnerability in this context is understood as the internal preconditions in a society or a social-ecological system that influence the potential to experience harm as a result of a given hazard (Thywissen 2006: 477 ff.). Compared to vulnerability, risk—in the disaster risk research community –can be understood as the product of the interaction of a given hazard and a vulnerable societal system that is exposed to this hazard (see e.g. UNISDR 2004). Definitions of risk often also encompass the probability of hazard occurrence. However, for some hazards in the context of climate change such as sea level rise the probability concept cannot be applied. In general, effective risk reduction and risk management strategies require an improved understanding of the vulnerabilities of communities at risk.

In contrast to approaches that mainly associate risk with the occurrence of a natural phenomena or hazard event, vulnerability and resilience research highlight that the impact of a hazard event is strongly shaped by the human action and by the internal conditions of social systems as well as their coping and adaptive capacities (Hewitt 1983; Oliver-Smith 1999; Wisner/Blaikie/Cannon et al. 2004; Müller-Mahn 2005; Birkmann 2006a). While in the 1980s and 1990s this discussion was mainly informed by researchers working in the field of disaster risk reduction and development research, the discussion today also involves the climate change community. Most notably, the report SREX from the Intergovernmental Panel on Climate Change (IPCC 2012a) addresses new challenges of dealing with extreme weather events through the lens of vulnerability and risk. An in-depth discussion of different definitions of vulnerability and the relevance for spatial planning can be found in Birkmann (2006a) and Birkmann (2008) and also in a more recent review of applied vulnerability concepts in regional planning (BMVBS 2011).

While Birkmann (2008) provides an overview of different schools of thought, BMVBS (2011) summarises the application of vulnerability assessments within selected regions in Germany. The review of BMVBS (2011) also highlights that in some cases vulnerability has been understood in terms of impact assessments, while other approaches, for example in the region of Stuttgart, have clearly applied an analysis which focuses on the three core components of vulnerability: exposure, susceptibility or sensitivity and societal capacities (in terms of coping and/or adaptation). Due to the intensive discussion of different vulnerability concepts by the research mentioned above, this paper makes reference to the definitions used, rather than repeating the detailed arguments.

2.3 Resilience

The term resilience emerged largely within two areas: the ecology and stability research undertaken particularly by Holling (e.g. Holling 1973) and research in the field of psychology which examined the question as to why some people are better able to cope with major traumata than others (see e.g. Garmezy/Masten/Tellegen 1984; Rutter 1985; Werner 1992; Luthar/Cicchetti 2000; Masten/Powell 2003). While ecological resilience research developed further to focus on coupled social-ecological systems (see e.g. Berkes/Col-

Table 1 Concepts of resilience. (Source: Folke (2006: 259))

Resilience Concept	Characteristics	Focus on	Context
Engineering Resilience	Return time, efficiency	Recovery, constancy	Vicinity of stable equilibrium
Ecological/ecosystem resilience and social resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibria, stability landscape
Social-ecological resilience	Interplay, disturbance and reorganization, sustaining and developing	Adaptive capacity, transformability, learning, innovation	Integrated system feedback, cross-scale dynamic interactions

ding/Folke 2003), the psychological resilience research still focuses primarily on the internal attributes of the individual, such as confidence, trust, sense of community. Interestingly, recent work on psychological resilience has increasingly moved towards a multilevel perspective, one including a concern for the role of the family and community.

Today the debate on resilience is heavily influenced by the Resilience Alliance[6], which focuses on so-called coupled social-ecological systems. The underlying hypothesis is that social and environmental systems are not separate entities or regimes, but are instead characterized by close inter-dependencies (see for example Berkes/Colding/Folke 2003). Social and ecological systems are interwoven and often connected within one regulative regime, e.g. in terms of material as well as non-material flows and interactions (see in detail e.g. Walker/Holling/Carpenter et al. 2004). However, whether these systems really operate with similar regimes and how coupling processes and resilience building can be assessed are ongoing subjects of debate in resilience research. Resilience theory stresses, for example, that 'adaptive cycles' and the 'panarchy' model[7] can be used to describe and explain reorganisation processes within social-ecological systems. Whether in this context resilience is linked to the notion of resistance and stability or whether it implies fundamental changes and reorganization processes in the light of crises remains contested.

Overall, resilience has become a popular concept to describe and analyse crises and dynamics of and within social-ecological systems, focusing particularly on the interplay between robustness or stability, disturbances and reorganisation processes. The resilience concept has changed significantly as it has been taken up by different schools of thought, as Folke (2006: 259) outlines (see Table 1).

In the light of climate change adaptation and the needs of spatial planning, the translation and application of the concept of resilience remains a challenge. While resilience can be interpreted as robustness (e.g. Dosch/Porsche 2008; Birkmann/Fleischhauer 2009), it is also argued that resilience requires flexible structures that can also be modified in response to the ongoing process of climate change and adaptation (e.g. Birkmann 2011). Therefore, it is important to acknowledge that as a term and concept resilience has evolved: from a primary concern for environmental issues towards a broader concept that focuses on adaptive capacity, transformability and learning processes. Hence, an understanding of resilience as robustness fails to acknowledge this broader debate. An overview of additional key terms in the context of climate change and spatial planning and their different definitions can be found in a new glossary developed by a working group of the Academy of Spatial Planning (see Birkmann/Böhm/Buchholz et al. 2011).

From this discussion of key terms the next section introduces a conceptual approach to examining vulnerability which is an important pre-requisite for increasing resilience. This approach will then be illustrated with reference to the vulnerability of people and critical infrastructure to floods in Cologne.

3 A Concept to Assess Vulnerability

Vulnerability approaches have been greatly influenced by the literatures on poverty, natural hazard research and development studies (see Wisner/Blaikie/Cannon et al. 2004; Turner/Kasperson/Matson et al. 2003; Birkmann 2006a). One of the most prominent examples is the Sustainable Livelihood framework (DFID 1999), which places emphasis on the acquisition, substitution and usage of different types of assets that an individual or household has for pursuing livelihood strategies. Further key influences on the debate on risk and vulnerability reduction include work in development research, where issues of poverty and entitlements play a key role (see e.g. Bohle 2001), research on general system theory and risk studies (see e.g. Cardona 1992; Birkmann 2006a) and approaches that focus on human-environ-

[6] See http://www.resalliance.org (accessed 12.04.2012).

[7] The adaptive cycles of individual systems are nested in a hierarchy across time and space. For example the ecosystem of a small lake (one individual system) is linked to larger group of lakes and river systems (with different spatial and temporal processes). These nested hierarchies between individual systems of adaptive cycles might have a stabilising effect due to their capacity to provide memory of the past and elements of the system that are distant. This can encourage recovery after disturbances occur in one specific system. The nested hierarchies and dependencies between different systems might also have a destabilising effect when dynamics across scales lead to a further positive feedback process, allowing small-scale transformations to occur and explode into large-scale crises. Taken together, these nested hierarchies between individual systems of adaptive cycles and the processes across time and space constitute the theoretical concept of "panarchy" (see Holling/Gunderson 2002: 25 ff.).

mental interactions and their vulnerability (see e.g. Turner/Kasperson/Matson et al. 2003).

The vulnerability concept used here, called BBC-framework (see in detail Birkmann 2006b: 34) has its roots in the development of a holistic approach to vulnerability assessment linked to a system-science perspective, e.g. linked to the concept of a feedback loop system and the theory of cybernetics (see e.g. Cardona 1999; Cardona 2001; Bogardi/Birkmann 2004). At its core, the concept differentiates key factors of vulnerability (exposure, susceptibility and coping capacity) and reveals different thematic dimensions of vulnerability, such as social, economic and environmental vulnerability. Both the assessment of the vulnerability of different social groups as well as of critical infrastructures refer to the social dimension, since the focus is primarily on the consequences of critical infrastructure breakdowns for people and not on the economic costs of such events.

In terms of the key factors of vulnerability, it is important to note that exposure is a contested area. In the conceptualisation of vulnerability, exposure describes the extent to which a unit of assessment falls within the geographical range of a hazard event. Exposure extends to fixed physical attributes of social systems (infrastructure) but also human systems (livelihoods, economies, cultures) that are spatially bound to specific resources and practices that may also be exposed. If a system or object is exposed, it does not necessarily mean that the system is vulnerable, since it might have a very low level of susceptibility and a high level of coping or adaptive capacity. Hence, susceptibility describes the predisposition of elements at risk (social and ecological) to suffer harm. The third factor that determines vulnerability is the response capacity of the community or system exposed, here expressed as coping capacities and capacities that allow for vulnerability reduction; that can be activated before and after disasters have occurred. The interventions, which aim to reduce vulnerability, are linked to the more recent term of adaptation. This means that while coping encompasses immediate response actions during a crisis or hazard event, adaptation is mainly linked to the response capacities to reduce vulnerability and hazard intensities in the medium and long run. Thus adaptation, in contrast to coping, implies a longer timeframe and a notion of planned, strategic, target-oriented and coordinated action. Though conceptually appealing, a clear-cut differentiation between coping and adaptation is often hard to achieve. The application of the concept to the case studies in this paper focuses primarily on selected indicators to assess exposure, susceptibility and coping capacities and also, in part, adaptive capacities.

4 Tools for Resilience Building: Vulnerability Assessment of People Exposed to Floods—Cologne Case Study

At present flood risks are mainly addressed in spatial planning through the designation of flood prone areas.[8] To determine these designated flood prone areas, spatial planning at the regional scale draws primarily on the HQ-100 flood events (representing a flood that statistically occurs once every 100 years). Areas are marked which could be inundated by an HQ-100 flood event. These are often areas between dyke systems. The recent EU Flood Directive on the assessment and management of flood risks[9] further emphasises that such flood hazard maps should encompass different flood scenarios: scenarios with low (extreme event), medium (likely return period ≥ 100 years) and high probability. Although it is clearly an improvement to move from a more static understanding of hazard maps towards the consideration of different flood scenarios, the lack of consideration of vulnerability and its dynamics remains a problem.

Against this background, this section introduces a flood vulnerability assessment that examines flood exposure, as well as susceptibility and the coping capacity of people and urban areas exposed. The methods and indicators proposed were developed in a research project funded by the German Federal Office for Disaster Prevention (BBK) that dealt with the assessment of vulnerability to flooding at the local level. One of the case study areas was the city of Cologne, whose municipal authorities provided data which was then supplemented by household-surveys and expert interviews conducted by the project researchers.

On the basis of the concepts introduced, a range of key dimensions of vulnerability need to be considered to achieve an integrated approach; addressing the exposure of people, as well as susceptibility and coping capacity. In order to measure these factors and to identify differences between various districts within Cologne, indicators are used that represent and quantify aspects of the exposure, susceptibility and coping capacity of people. The results of this assessment provide a preliminary insight and overview of key vulnerability characteristics in flood prone areas. This assessment may be useful in prioritising flood mitigation and vulnerability reduction measures applied by different stakeholders, civil protection or spatial and urban planning services.

The HQ-100 scenario and its spatial coverage were used as a basic information to assess the exposure of people to floods in urban areas in Cologne (see Fig. 1). In Germany,

[8] Vorrang- und Vorbehaltsgebiete für den vorbeugenden Hochwasserschutz.

[9] See http://ec.europa.eu/environment/water/flood_risk/index.htm (accessed 12.04.2012).

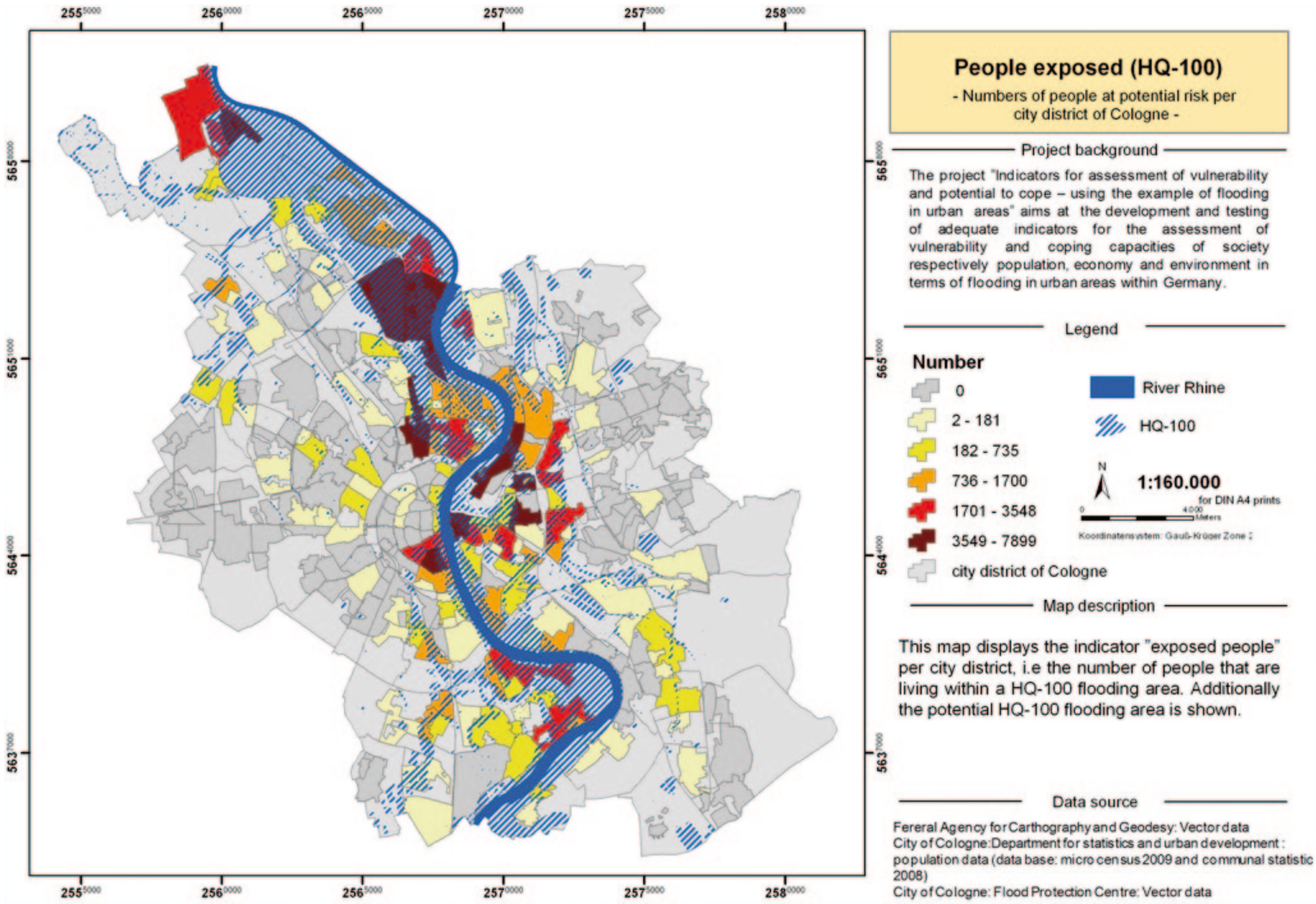


Fig. 1 Number of people exposed to an HQ-100 flood event in Cologne. (Source: Birkmann/Vollmer/Wolfertz (2010: 55))

the obligation to designate HQ-100 areas is defined in the Act to Improve Preventive Flood Control.[10] GIS data from local agencies was integrated with address data to generate an overview of the number of people (per district) that would be affected in case of such a flood event (assuming a failure of preventive measures). Exposure values across city districts in Cologne ranges from no people exposed (grey) to the exposure of more than 3500 people per district (dark red).

Although spatial and urban planners have a limited capacity to influence existing urban areas, it is evident that the exposure indicator could be helpful. In particular, it might support decision making on managing land use for preventive flood protection by complementing the purely physical information on flood prone areas. Furthermore, the increase of human exposure behind dyke systems should be a concern addressed by spatial planning strategies in the medium and long term. Indeed, instruments of the special Urban Planning Law (*Besonderes Städtebaurecht*) in Germany permit the consideration of patterns of exposure to flood risks in the context of urban renewal and urban reorganisation (see Greiving 2011: 26). This is particularly relevant for 'shrinking cities' and urban areas experiencing structural change–urban areas that need to be re-shaped through urban and spatial planning. In this regard, cities, planners and developers can revisit the existing type and density of housing and business areas and buildings with regard to flood exposure and the amount of people likely to be exposed (see also Hochwasserschutzzentrale Köln 2011). Legislation related to spatial planning such as the EU Flood Directive or the German Federal Spatial Planning Act (*Raumordnungsgesetz*) aim not only to provide an assessment of flood hazards, but also to reduce flood risk and the vulnerability of the exposed areas and infrastructures.

In a second step, indicators to assess the susceptibility and coping capacities of people exposed to floods were identified and tested. Besides the use of official statistical data, information was also derived from household interviews and a micro-census conducted by the Cologne municipal authorities.

The triangulation of different data sources allowed the indicators listed below to be derived (Birkmann/Krings/Vollmer et al. 2011: 114). Since the susceptibility as well as the coping capacity of people cannot be measured directly,

[10] Gesetz zur Verbesserung des vorbeugenden Hochwasserschutzes.

proxies were examined that enabled the identification of city areas and social groups that are likely to be more fragile during flood events. Additionally, indicators to help identify capacities of people to deal with flood events and flood losses were also developed. The "key indicators", those that only require official statistical data, already provide an overview, while the complementary "locally specific indicators" require specific surveys. Key indicators represent important aspects of the susceptibility and coping capacity of people and at the same time strongly correlate with official statistical data. Overall, in the context of the project the following proxies and indicators were selected and tested:

Susceptibility:

- Ability to evacuate without external help: key indicator, proxy: age-based household types (official statistics);
- Time people need to evacuate and move to safe places: key indicator, proxy: age-based household types (official statistics);
- Awareness of flood risks—peoples' estimation of their own flood risk: locally specific indicator (survey/census);
- Information about flood risk—flood risk information received/requested by people when they moved into their flat/house: locally specific indicator (survey/census).

Coping capacity:

- Potential insurance coverage: key indicator, proxy: household income (official statistics);
- Flood experience: key indicator, proxy: duration of occupancy (official statistics);
- Actual insurance coverage: locally specific indicator (survey/census);
- Flood protection measures taken by the city and citizens: locally specific indicator (survey/census).

The data regarding the awareness of flood risks, actual information about flood risks, actual flood insurance coverage and flood protection measures can be derived solely from a micro-census or household surveys. In contrast, the indicators "ability to evacuate", "time required to move to safe locations", "flood experience" and "potential flood insurance coverage" can be determined by statistical data using proxies (see Birkmann/Vollmer/Wolfertz 2010 or Birkmann/Krings/Vollmer et al. 2011 for further details). The ability to evacuate strongly correlates with the age structure of different household types, which can be derived from official statistics. For example, households with people older than 60 years are more often unable to evacuate without external support than those households with people aged between six and 59 years old. The survey also shows that elderly people are more likely to only have access to a weak social support network, when compared to households of working age (Birkmann/Krings/Vollmer et al. 2011: 119). Consequently, the demographic change in general increases the vulnerability of people to floods, since elderly people are much more likely to require external help during floods, as was revealed through the detailed household surveys conducted in Cologne and Dresden. In this regard, the indicators reveal urban districts with a higher amount of susceptible people with a stronger need for external support during crises. The proxies can thus support decision-making and planning processes through prioritising areas where flood protection and flood preparedness are most necessary (see also Fig. 2).

Although spatial and urban planning cannot directly influence the indicators selected to gauge susceptibility and coping capacity, the information about the areas where susceptible people are concentrated is crucial to spatial planning at the regional scale. The indicators for susceptibility and coping capacity provide an important bridge between spatial and urban planning and civil protection. Preventive strategies for vulnerability reduction and resilience building require a closer link between urban and spatial development and civil protection e.g. in terms of shelter planning or the security of critical infrastructures etc.

The question as to whether people are insured against damages caused by flooding is an important indicator for the coping capacities of different social groups and urban areas concerning the recovery potential in the aftermath of a flood. Those major flood events that trigger sufficient media attention often result in the distribution of public funds to affected people. However, it should be noted that, as a result of climate change, an increase in small and medium flood events is likely. Such floods may cause low damages but will occur more frequently. In this context the spatial distribution of flood insurance coverage between different city districts can provide important information about the potential economic coping capacity of an area and the respective households once such flood damages occur. In Cologne, for example, the southern districts are populated by relatively wealthy people. Although these areas are potentially more exposed to higher economic losses, at the same time most households have a significantly higher amount of flood insurance coverage in comparison to areas in the northern part of the city or the city centre. Being insured against flood losses in Cologne correlates significantly to the income of a household (see Fig. 3[11]). However, it is interesting to note that usually flood insurance is relatively cheap. Therefore, it is very likely that the agents selling flood insurance mainly target wealthy areas, since they expect that households with a higher income might be more willing to pay for such additional protection—irrespective of the question as to whether poorer households would also be able to afford it.

[11] The results refer to households in the HQ-500 area (including HQ-100), since the data set for households exposed in HQ-100 was not sufficiently reliable for this analysis.

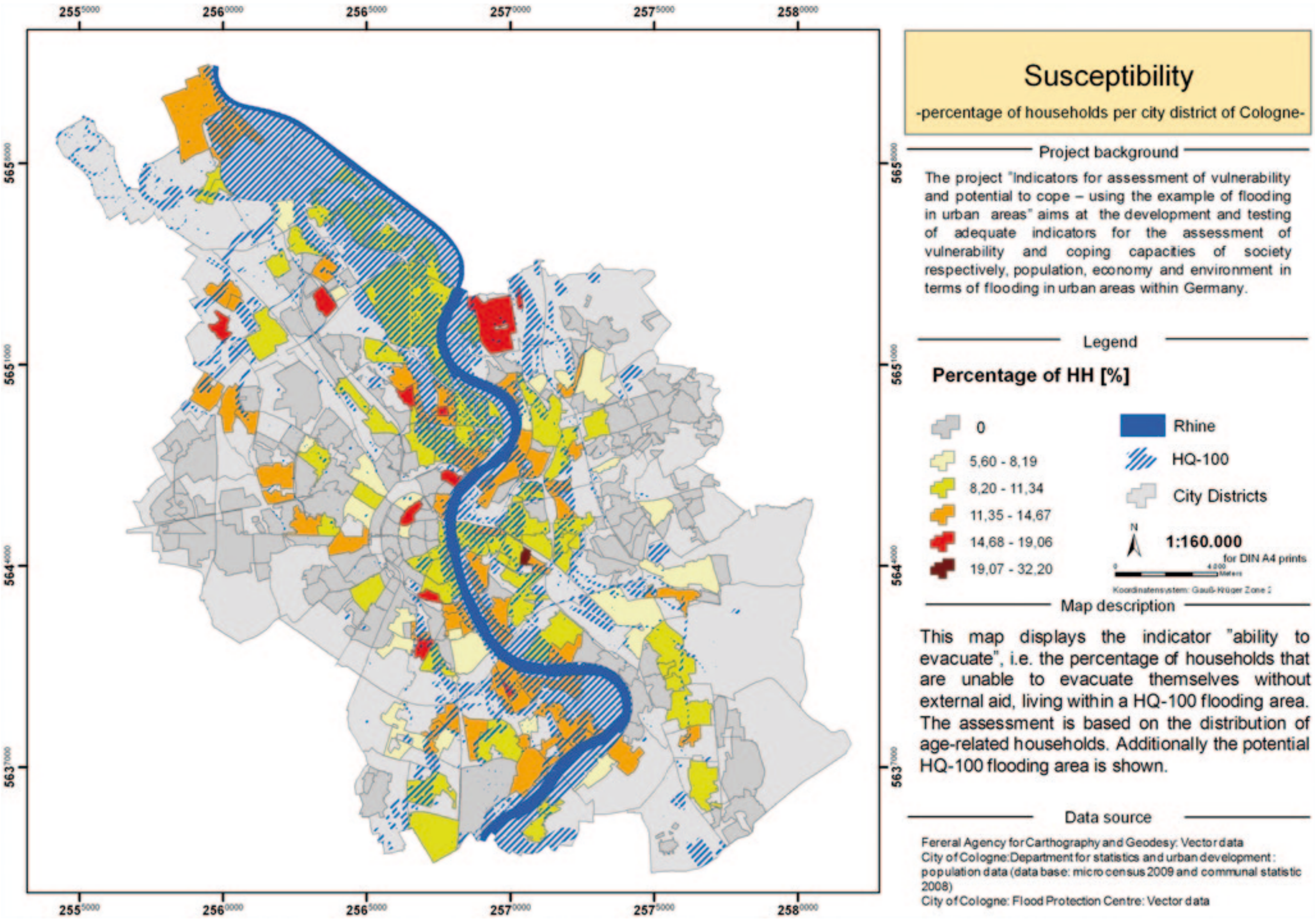
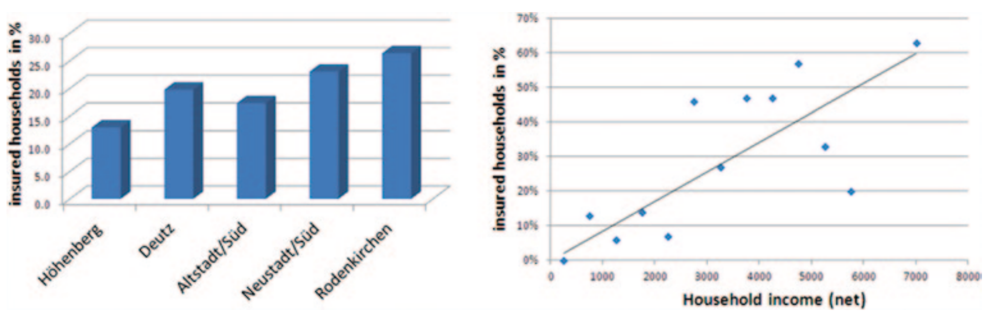


Fig. 2 Susceptibility—ability to evacuate. (Source: Birkmann/Vollmer/Wolfertz (2010: 58))

Fig. 3 Insured households in selected urban districts in Cologne; correlation between household income and insurance. (Source: Own figure based on Birkmann/Krings/Vollmer et al. (2011: 126 and 167))



Although the above indicator has no direct link to spatial planning, it does, however, illustrate precisely that exposure alone is not sufficient to characterise vulnerability to floods or climate related hazards. Furthermore, it underscores that the different vulnerability components described in the theoretical framework can be applied at the local and regional level.

An additional example of an indicator to assess coping capacity is the experience people have or potentially have with floods where they live. The time period that people have been living in Cologne at their place of residence was used as a proxy since it strongly correlates with their experience concerning flooding based on the household survey. People who have been living in the city since at least 1994 will have experienced the 1995 flooding and are, therefore, more likely to already have knowledge of coping processes. Additionally, the results of the household survey showed that people who have been affected by floods have a higher degree of preparedness and are also less likely to suffer psychological illnesses as a result of flooding (Birkmann/Krings/Vollmer et al. 2011: 124).

The indicators outlined above, which have been illustrated in diagrams or shown in maps, highlight areas and social groups that are most vulnerable or those groups that have lower coping capacities. In this context, the vulnerability assessment underscores that risks and vulnerability related to flooding are not a result of natural phenomena, but are rather determined by social conditions and processes.

The following section adds greater depth to the discussion on how to assess vulnerability within exposed areas using the case study of critical infrastructures, which are, as the Fukushima crisis starkly revealed, crucial to spatial and regional development.

5 Tools for Resilience Building: Vulnerability Assessment of Critical Infrastructures

Critical infrastructures are defined as "those systems and system components that have a vital importance to a nation's society and economy since their failure or degradation would result in sustained supply shortages, significant disruption of public safety and security, or other dramatic consequences"(German Federal Ministry of the Interior 2009: 4). In industrialised countries, these services are highly interconnected and dependent on each other. For example, power supply serves as a basic infrastructure to all other services (in most regions). A major blackout would lead, amongst other things, to failures in information and communication technology, shortages in water supply and sewage treatment as well as disruptions in transport and health services (Reichenbach/Wolff/Göbel et al. 2008: 22 ff.; Lauwe/Riegel 2008: 118 ff.). Critical infrastructures consist of complexities (Rinaldi/Peerenboom/Kelly 2001: 13) that have increased during the last two decades for several reasons. Firstly, infrastructure systems have become more and more dependent on each other, especially as a result of the growing importance and use of information and telecommunication technology. Secondly, the creation of a European market brought with it the privatisation of formerly state-owned companies and the increase of actors in markets. This complexity has to be considered when assessing the vulnerability of critical infrastructure systems because disruptions may lead to (unforeseen) effects that could even entail cascading effects on further infrastructure sectors (Rinaldi/Peerenboom/Kelly 2001: 13 ff.; IRGC 2006: 22 ff.; Hellström 2007: 417 ff.; Kröger 2008: 1781). Although assessments and indicators cannot capture all of these complexities, they provide a preliminary method to systematize some of the key aspects that constitute complex interactions, for example with regard to technical and staff redundancies. Although residual risks from the cascading effects of unforeseen failures cannot be solved by indicators, the vulnerability assessment of critical infrastructures can help to systematically capture and communicate risks.

The Fukushima crisis with its interrelated problems resulting from a natural hazard (earthquake and tsunami), a technical failure within the cooling system of a nuclear power-plant and the constraints of the crisis management processes thereafter, is emblematic of the fact that even so called modern societies are vulnerable to natural hazards due to their development process. For example after the crisis, the street lights in Tokyo had to be shut down due to energy shortages with the consequence that a major infrastructure (road systems) did not work properly in the urban agglomeration of Tokyo. A crisis of this magnitude has yet to occur in Germany. Nonetheless, the severe damages and failures of critical infrastructures during the Elbe Flooding in 2002, with damages to infrastructures (municipally-owned and federal) amounting to 50 % of the overall damage caused and accounting for almost 5 billion Euros, revealed the importance of these infrastructures as well as their vulnerability (Mechler/Weichselgartner 2003: 18 f.).

The increased dependency of modern societies on critical infrastructures, and their rising potential for disruption (e.g. as a result of natural hazards), has also triggered a wider concern for how to improve the protection of critical infrastructures. Besides national strategies, the protection of critical infrastructures is increasingly prominent at the EU level. A recent EC directive (2008/114/EC)[12] underlines the importance of critical infrastructures and defines those infrastructures and processes in the area of energy and transport that should be examined and monitored. Additionally, the German Federal Government has identified spatial planning and civil protection as two key policy areas that should consider critical infrastructures and their protection against extreme weather events. The adaptation of spatial structures, including infrastructure systems, has also to be taken into account (Bundesregierung 2008: 44 f.) in order to promote sustainable spatial development. Against the background of the strategies outlined before, the following section describes how a vulnerability assessment for critical infrastructures could be carried out at a meso-level in terms of its technical details for flooding.

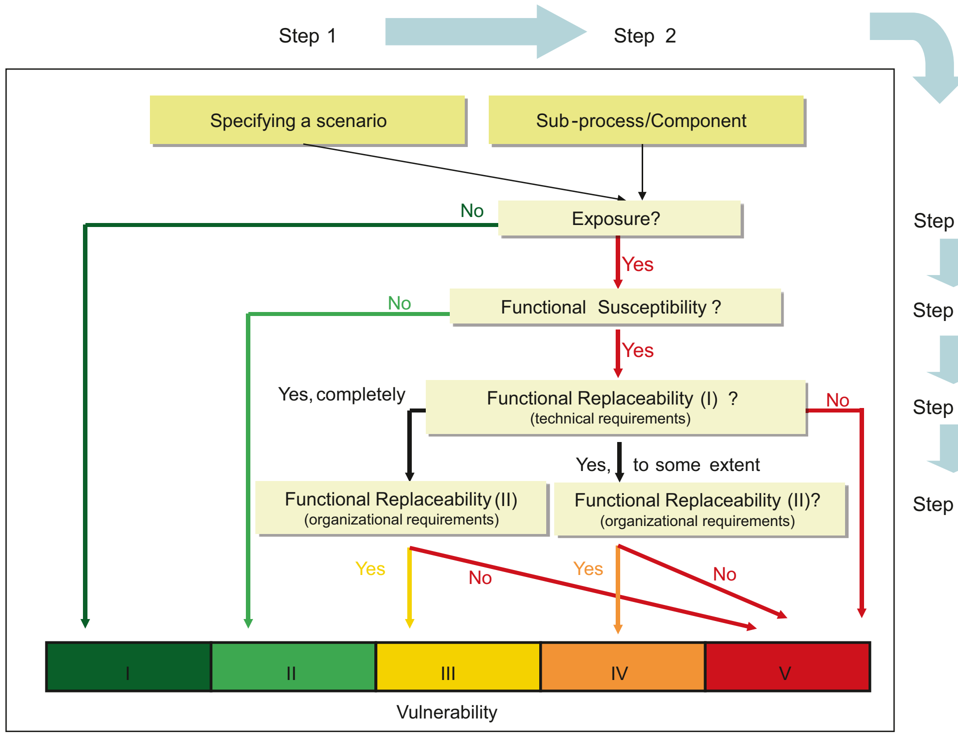
Regarding vulnerability assessments for critical infrastructures, two categories of natural hazards have to be distinguished: sudden onset and slow onset hazards[13]. In terms of sudden onset hazards, this section will outline an assessment method for the example of flooding. For slow onset hazards, a more general overview of assessment methods is given and the special role that complexity plays in this context is underscored.

With the increasing importance of critical infrastructures, several approaches have been developed to concep-

[12] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:345:0075:0082:EN:PDF.

[13] Slow onset hazards, in contrast to sudden onset hazards, emerge gradually over time. The most common example of a slow onset hazard is drought. Sudden onset hazards instead encompass e.g. earthquakes, tsunamis, floods, tropical storms, volcanic eruptions and landslides.

Fig. 4 Assessment framework for critical infrastructures—flooding. (Source: Krings (2010: 25))



tualise critical infrastructures and their vulnerabilities (see, amongst others, Rinaldi/Peerenboom/Kelly 2001; IRGC 2006; Hellström 2007; Lauwe/Riegel 2008; Kröger 2008; Lenz 2009). However, most approaches remain either very general or focus on one specific detail, and do not provide a systemic overview of the overall vulnerability of a system, its components and processes. Rinaldi/Peerenboom/Kelly (2001), for example, describe the complexity of infrastructure systems by categorising, *inter alia*, types of interdependencies or coupling and response behaviour. In contrast, Hellström (2007) analyses root causes, dynamic pressures and unsafe conditions by adapting Wisner/Blaikie/Cannon et al. (2004). Although qualitative analysis in the field of vulnerability assessments of critical infrastructures represents an important step forward, quantitative approaches that could facilitate comparative or progress assessments are generally still neglected.

In order to quantify the vulnerability of critical infrastructures, an assessment framework (see Fig. 4) for flooding was developed by Krings (2010), following the vulnerability concept consisting of exposure, susceptibility and coping capacity. Krings developed a semi-quantitative method, since quantitative data was not sufficiently available or accessible, due to the fact that most of the information rests within private companies who run such critical infrastructures. Moreover, the semi-quantitative approach avoids a false sense of preciseness, since some of the key challenges cannot be sufficiently expressed in quantitative terms alone. It thus takes into account those effects of complexity that cannot be fully assessed in quantitative terms. The semi-quantitative assessment is instead supported by questionnaires that capture core factors of vulnerability such as exposure, susceptibility and coping capacity using proxies.

In a first step, “exposure” to floods was assessed by using a specific flood scenario, e.g. the HQ-100 or HQ extreme (HQ-500 for Cologne). This scenario was combined with a GIS map of critical infrastructure components (and respective processes that are processed by these components) to assess those components potentially exposed to floods. The exposed components might experience disruptions or even stop functioning as a result of inundation. In order to derive information on the concrete effect of an inundation on the component, expert interviews were conducted. These expert interviews allowed for an evaluation of the potential for failure and thus the susceptibility of the respective component.

The coping capacity of the critical infrastructure was then assessed by focusing on technical redundancy as well as organisational and institutional preparedness and redundancy within the system. While technical redundancy refers to whether another component would be able to replace the susceptible component, organisational and institutional preparedness focuses on the question as to whether personnel would be available to manage such shifts and to undertake the changes necessary in a situation of crisis (Krings 2010: 25 ff.).

Following these steps, each process (in relation to the electricity supply example) can be classified in terms of the exposure of the sub-components involved, the susceptibility of the components and the coping capacity (assessed in terms of technical redundancy and organisational prepared-

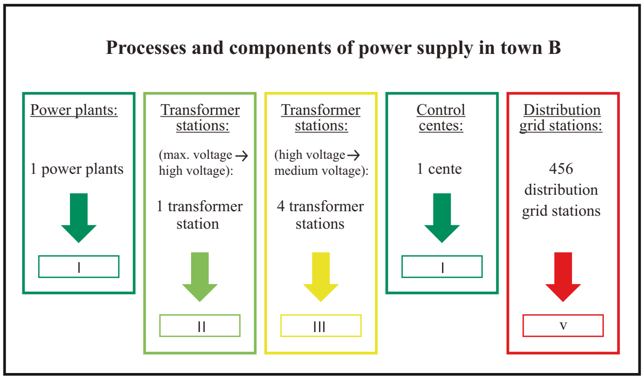


Fig. 5 Vulnerability assessment for critical infrastructures in town B (fictive case study). (Source: Own figure based on Krings (2010: 169 ff.))

ness which allows for the classification of a specific level of vulnerability). For example, when a component or process was not exposed in the flood scenario it was automatically classified as not vulnerable to the flood as such. Compared to that, a system component that was exposed, susceptible, and had a low coping capacity was judged to be very vulnerable using an ordinal classification scale (see Figs. 4 and 5[14]).

The analysis of the vulnerability of the overall system by looking step by step at individual components and processes, allowed for an integrated analysis that can also inform respective protection and adaptation strategies. Such strategies can encompass the relocation of important infrastructure components or modification of the network to better contain the cascading effects at a local scale. The adoption of protection measures such as the shift of local distribution stations to higher ground has been one strategy implemented since the major flood events on Rhine and Elbe in Germany. In particular, the relocation of different key components of such critical infrastructure networks or the conservation of redundant structures has an important spatial dimension that needs to be considered more effectively in spatial and urban planning in the future. Aspects of decentralisation and the further integration of renewable energies, with their respective challenges for the security of a system, are of high relevance here.

Overall, the framework developed is a first step in systematically assessing the vulnerability of critical infrastructures and power supply—in particular to flood hazards—through the application of a semi-quantitative approach. While the identification of exposure in critical infrastructures is relatively easy to perform in terms of sudden onset hazards such as river flooding or flash floods, it is much more complex to assess the vulnerability of critical infrastructures to slow onset hazards such as heat waves. Although slow onset hazards affect vast areas (exposure), they do not often physically destroy the components of critical infrastructures. An assessment of functional chains and qualitative assessments is required in order to understand their vulnerabilities. For example, in terms of heat stress, in 2003 almost all of Western Europe was affected by the heat wave (BfG 2006: 15). The heat wave in combination with low water levels in larger river systems caused a series of conflicts between the need to use the remaining water in the rivers for cooling processes of power plants and the need to maintain the balance of the already stressed water river system (protection of the ecological functions of rivers). Nuclear and coal-based power stations need about 50 l of fresh water for rod cooling to produce one kilowatt hour of electricity (Lönker 2003: 23). Due to the need to also consider the ecological functions in large river systems, and their survival during the heat wave, several power plants along large rivers in Germany had to reduce their energy production. In some cases nuclear and coal-based power plants had a reduced energy production of between −15 % and −100 % during the heat wave in 2003 (BfG 2006: 185). At the same time people began using additional technical devices, such as air-conditioning, which actually increased the demand for energy during this period (BfG 2006: 184). Consequently, the tension between reduced energy production and the increasing demand during a heat wave can lead to larger forms of stress and dysfunction within energy supply systems.

Furthermore, many coal-based power plants rely on coal supplied by ship. Accordingly, in times of low tide these logistical linkages might also not function well (BAG 2003: 27). Hence, future assessments of the appropriate locations for such power plants (as one example) need to go beyond the analysis of the direct environmental impacts of the power plant on the environment. Rather than just focusing on the environmental impacts of the construction of such power plants, the questions of whether and how different environmental conditions in the light of climate change (including low water levels) might influence the operation of energy generation and thus shape the set-up of power supply.

As such, new and additional criteria that go beyond the existing framework for assessing the effects and vulnerability of critical infrastructures to slow-onset hazards are required.

[14] Each process is classified according to the component with the highest vulnerability. Whereas the components of power generation and control centres are not exposed, transmission from maximum voltage to high voltage is exposed, but would continue working when flooded due to flood protection measures. Two of the four transformer (from high to medium voltage) stations are susceptible to flooding but redundant (class III). Most of the distribution grid stations are susceptible to flooding but not redundant and are therefore classified in the highest vulnerability class (V).

6 Outlook: Scenarios as a Supporting Tool for Resilience Building and Adaptive Spatial Planning

Although there is a large body of literature on governance in spatial planning, here the notion of "adaptive spatial governance" is utilised to challenge the view that adaptation in spatial planning rests largely on the adjustment of physical structures. The concept of adaptive governance described in this section outlines selected challenges and key dimensions of adaptive spatial governance. These have, at least implicitly, been mentioned already, but are further detailed here e.g. challenges with regard to scale or knowledge (see Fig. 6) that need to be addressed in order to enhance spatial planning towards adaptive spatial planning. The outlook therefore addresses challenges that go beyond traditional norms and legal-planning regulations, e.g. with regard to future scenarios of vulnerability. Beside the 'normative dimension' of adaptive spatial governance, the information and data used in planning decision making is also revisited and critically discussed (knowledge dimension), for example with regard to the limited future oriented use of scenarios of vulnerability.

While most legal planning decisions are based on thresholds and clear cut-off values, for example in terms of noise protection or air pollution, the issue of climate change requires a different focus. In this regard, the case studies presented here emphasise the point that risks and vulnerabilities are often socially constructed. Accordingly, local or regional specific assessments should be used as a basis for planning instead of generic values. Spatial planning decisions, it can be stated, are of most relevance to the long-term. Consequently, methods also need to be improved in terms of the development of scenarios for different development pathways. Furthermore, the criteria and indicators selected and presented show that societies and planning authorities can influence the further development of different trends and thus vulnerability patterns.

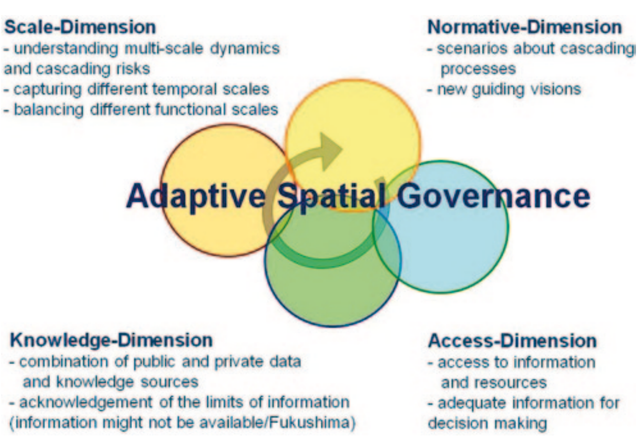


Fig. 6 Challenges for adaptive spatial governance

The systematic improvement and application of scenarios is a vital tool for resilience building since it allows for the juxtaposition of different development ideas with certain strategies and guiding visions already established. The exposure of people and critical infrastructures to floods, heat waves, and flash floods will definitely change due to the modification of hazard patterns influenced by climatic change. At the same time, however, demographic change, changes concerning the access to information via new technologies such as the internet or smart phones, will also alter the susceptibility and coping capacity of people. Furthermore, contrasting trends such as a further centralisation of critical infrastructures or, on the opposite extreme, a strong decentralisation, will have a severe impact on the susceptibility and coping capacity of these systems in the future. For example, a future scenario in the energy sector could imply that regions will deal with a further increase of renewable energies and the decentralisation of systems at the same time, which could reduce the vulnerability of critical infrastructures (Sperling/Hvelplund/Mathiesen 2011: 1340). However, in contrast, another scenario might be that due to the increased incorporation of renewable energies such as wind energy, the tensions within the system might increase and lead to failure and breakdowns of energy supply more often.

Overall, the consideration of different (future) scenarios of vulnerability in terms of societal development as well as the development of critical infrastructures needs to be improved. This can be supported through spatial and urban planning processes, particularly if approaches go beyond conventional deterministic planning approaches. In this regard, resilience building requires, alongside climate change scenarios, the further enhancement of societal development scenarios that complement and enhance the assessment of vulnerability.

At the global level, a new generation of scenarios for the Intergovernmental Panel on Climate Change is currently in development. This will outline scenarios that inform—like the old scenarios—mitigation policies, but will also include scenarios designed to inform adaptation policies. Particularly for the latter, closer monitoring of the type of urbanisation processes, the trends in demography and the trends in integrated governance are key issues to consider. It is necessary to move spatial planning away from the static and deterministic consideration of certain thresholds such as the flood HQ-100 lines. An improved consideration and development of different future scenarios in social vulnerability and the vulnerability of critical infrastructure would be an important innovation and means of enhancing the resilience of regions and cities in the light of climate and societal change.

In this context, adaptive spatial governance needs to address challenges related to spatial and temporal scales of different phenomena but also functional scale mismatches—acknowledge the different functional regimes natural and social systems operate with. Clearly, some of the scenarios have a time span that goes far beyond traditional considerations in urban and regional planning documents. In addition to the challenges linked to scales, the access to information also has to be improved. Here vulnerability assessments and scenarios should become part of the spatial monitoring and information system. Further, challenges and constraints of the normative systems used in spatial planning and civil protection need to be revisited. While most of the assessments used today such as environmental impact assessment mainly consider specific thresholds of sectoral laws, resilience building requires a stronger emphasis on processes and the integration of different scenarios or cascading effects that go beyond the scope of an individual project or plan.

Lastly, the knowledge dimension is crucial. Particularly in the context of critical infrastructure most information is gathered by private companies that are—as the Fukushima case showed—not always willing and in the position to make such information available to the general public in crisis situations. Hence, adaptive spatial governance needs to establish a new mechanism whereby these different types and sources of knowledge can be brought together and conflicts between different types of knowledge moderated. Figure 6 illustrates some of the key challenges of adaptive spatial governance, without aiming to be comprehensive.

In summary, the paper has highlighted the need to improve tools and measures for resilience building, to go beyond deterministic approaches and a static understanding of risk and acknowledge that vulnerability and risks are, in fundamental ways, socially determined and therefore also dynamic. These dynamics and different future development pathways have to be recognised and systematically incorporated into future planning processes. The above-mentioned examples of social vulnerability and critical infrastructure vulnerability have clearly illustrated these needs, while preliminary means of dealing with these challenges have been presented.

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