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Urban Disaster Resilience and Critical Infrastructure

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Habilitationsschrift

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Content

ABBREVIATIONS 4

ACKNOWLEDGEMENTS 4

SYNTHESIS GUIDE AND KEY PUBLICATIONS 5

1. PROBLEM STATEMENT AND RESEARCH QUESTIONS 9
Problem fields in summary 11
Research Intention 12

2. STATE OF THE ART IN THE FIELDS OF URBAN RESILIENCE AND CRITICAL INFRASTRUCTURE 12

2.1 Resilience and vulnerability as predominant concurrent concepts in disaster risk and security research 13

2.2 Resilience of settlements and resilient cities as a specific research topic 19

2.3 Critical Infrastructure Protection and Resilience 19

Main findings of chapter 2 - 'State of the art in the fields of urban resilience and critical infrastructure' 23

3. GAPS IN CURRENT RESEARCH AND PRACTICE 25

3.1 Conceptual gaps 25

3.2 Gaps in Methods and Measurements 26

Main findings of chapter 3 'Gaps in Current Research and Practice' 27

4. CONCEPTUAL MODEL AND METHODS USED IN THIS STUDY 29

4.1 Phenomenon context: Natural and man-made risks in a disaster risk management paradigm 30

4.2 Risk handling paradigm 31

4.3 Resilience 32

4.4 Criticality 35

4.5 Infrastructure 35

4.6 Research area 36

4.7 Criticality assessment 36

4.8 A concept for merging technical systems and humans in criticality assessment of infrastructures (Three indirect impact layers of infrastructure failure) 37

Application of the concept 38

4.9 Conceptual resilience components useful for the analysis of critical infrastructure 39
Differentiation of vulnerability and resilience components in context to place-based assessments of Critical Infrastructure 40
Narrow conception of resilience useful for operationalisation 42

4.10 A concept for a place-based assessment in urban areas or regions concerning their critical values, infrastructure services and most vital elements 46

Main findings of chapter 4 'Conceptual Model and Methods Used in This Study' 50

5. CASE STUDY – EX-ANTE RISK AND RESILIENCE ASSESSMENT OF AN URBAN AREA USING GIS: COLOGNE AREA 53

5.1 The Conception and Methodology 53
Methodology 54

5.2 Results of the Assessment 56

5.3 Discussion of case study results 61

5.4 Conclusions 63

Main findings of chapter 5 'Case study' 64

6. SYNOPSIS AND PERSPECTIVES OF AN EMERGING RESEARCH FIELD 65

6.1 Synopsis of the work presented in this volume 66

6.2 Additional Perspectives for this field 69
Integrative resilience concepts 69
Contributions to disaster risk management and governance 71
Incentives for the critical infrastructure and urban resilience nexus: Minimum supply concept 73
Context and contribution to (German) geographical risk research 74
Final conclusion – urban disaster resilience and critical infrastructure - a new thematic research field 77

FIGURES 79

TABLES 80

LITERATURE 81

Abbreviations

CCA	Climate Change Adaptation
CI	Critical Infrastructure
CIP	Critical Infrastructure Protection
CIR	Critical Infrastructure Resilience
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
ITC	Information Technology and Communication
HFA	Hyogo Framework for Action
RMCM	Risk and Crisis Management
SFDRR	Sendai Framework for Disaster Risk Reduction

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Synthesis guide and key publications

This volume describes an emerging research field - risk and resilience assessments in context to urban areas and critical infrastructure. It provides an overview of key work carried out by the author over the period from 2012-2017. This volume consists of several papers and book chapters published. The key methods and findings of each paper are summarised. The 10 papers, 2 book chapters as demanded for the habilitation thesis by the University of Würzburg (see Table 1), additional publications relevant for this volume by the author (Table 2) and 50 pages of additional explanation and framing text are brought into a logical sequence that starts with an overview on the thematic field, explanation of conceptual model used, followed by case study assessments and concludes with an outlook on future fields for research and transferability (see Figure 1). Please see an overview on the publications by the author that serve as a basis and repository for more detailed information regarding this volume below.

Habilitation topic: „Urban Disaster Resilience and Critical Infrastructure"
Start of habilitation process: 4.7.2012

Publications as required by agreement on achievements

1. At least six peer-reviewed international journal-papers as first author

Result: 6 published, 5 with ISI and 1 with SCIE index. 6 out of 4 in journals related to „Geography" in „Aims and Scope".

2. Two ISBN, peer-reviewed book chapters as first author

Result: 2 published

3. At least four peer-reviewed international journal-papers as co-author

3 published, 1 in revision

4. An extensive synthesis, at least 40-50 pages

Ready – in this volume

5. Conclusions and perspectives, at least 5-10 pages; showing research requirements.
Ready – in this volume

Table 1 Overview on publications relevant for this habilitation (target requirements)

Nr	Publication	Type
P1	**Fekete**, Alexander, Grinda, Christiane, Norf, Celia (2017) Resilienz in der Risiko- und Katastrophenforschung - Perspektiven für disziplinübergreifende Arbeitsfelder, in: Wink, R. (ed.) „Multidisziplinäre Perspektiven der Resilienzforschung". „Studien zur Resilienzforschung (Bd. 1)" Springer, Wiesbaden: 215-232. ISBN 978-3-658-09622-9.	Book chapter
P2	**Fekete** A (2012) Ziele im Umgang mit "kritischen" Infrastrukturen im staatlichen Bevölkerungsschutz. In: Managementhandbuch Sicherheitswirtschaft und Unternehmenssicherheit. Stuttgart: Boorberg Verlag. p. 1103-1124. ISBN 978-3415047761	Book chapter
P3	Birkmann, Jörn and Friedemann Wenzel, Stefan Greiving, Matthias Garschagen, Dirk Vallée, Wolfgang Nowak, Torsten Welle, Stefan Fina, Anna Goris, Benedikt Rilling, Frank Fiedrich, Alexander **Fekete**, Susan L. Cutter, Sebnem Düzgün, Astrid Ley, Markus Friedrich, Ulrike Kuhlmann, Balthasar Novak, Silke Wieprecht, Christoph Riegel; Annegret Thieken, Jakob Rhyner and James K. Mitchell (2016) Emerging research issues on the nexus: extreme events, critical infrastructures, human vulnerability and strategic planning. Research needs from an interdisciplinary and European perspective. Journal of Extreme Events. Vol. 3, No. 2 1650017 (25 pages) DOI:	Journal article (peer-reviewed)

	10.1142/S2345737616500172	
P4	Bach C., Bouchon S., **Fekete** A., Birkmann, J., Serre D. (2013) Adding value to critical infrastructure research and disaster risk management: the resilience concept. in Special Issue „Resilient Cities", S.A.P.I.EN.S [Online], 6.1 | 2013, Online since 15 July 2014, connection on 22 July 2014. URL : http://sapiens.revues.org/1626: 1-12.	Journal article (peer-reviewed)
P5	**Fekete**, A. (2012) Safety and security target levels: Opportunities and challenges for risk management and risk communication, International Journal of Disaster Risk Reduction: 67-76. http://dx.doi.org/10.1016/j.ijdrr.2012.09.001.	Journal article (peer-reviewed)
P6	**Fekete**, A., Lauwe, P. and Geier, W. (2012) Risk management goals and identification of critical infrastructures, Int. J. Critical Infrastructures, Vol. 8, No. 4: 336–353. DOI: 10.1504/IJCIS.2012.050108.	Journal article (peer-reviewed)
P7	**Fekete**, Alexander, and Patrick Sakdapolrak (2014) Loss and Damage as an Alternative to Resilience and Vulnerability? Preliminary Reflections on an Emerging Climate Change Adaptation Discourse. International Journal of Disaster Risk Science 5, no. 1 (2014/03/01): 88-93. DOI 10.1007/s13753-014-0012-7.	Journal article (peer-reviewed)
P8	Wrathall, David J.; Oliver-Smith, Anthony; **Fekete**, Alexander; Gencer, Ebru; Reyes, Marqueza Lepana; Sakdapolrak, Patrick (2015): Problematising loss and damage. In: International Journal of Global Warming (IJGW), Vol. 8, Nr. 2, S. 274–294. DOI: 10.1504/IJGW.2015.071962	Journal article (peer-reviewed)
P9	**Fekete**, Alexander, Gabriele Hufschmidt, and Sylvia Kruse (2014) Benefits and Challenges of Resilience and Vulnerability for Disaster Risk Management. International Journal of Disaster Risk Science 5, no. 1 (2014/03/01): 3-20. DOI 10.1007/s13753-014-0008-3.	Journal article (peer-reviewed)
P10	**Fekete**, Alexander, Katerina Tzavella, Roland Baumhauer (2017) Spatial exposure aspects contributing to vulnerability and resilience assessments of urban critical infrastructure in a flood and blackout context. In: Special Issue by Taubenböck / Geiß „Remote sensing for multi-scale mapping", Natural Hazards, 86(1) 151-176. DOI 10.1007/s11069-016-2720-3.	Journal article (peer-reviewed)
P11	Tzavella, Katerina; **Fekete**, Alexander; Fiedrich Frank (2017) Opportunities provided by Geographic Information Systems and Volunteered Geographic Information for a timely Emergency Response during flood events in Cologne, Germany. In Special Issue in Natural Hazards: "Recent innovations in hazard and risk analysis" by Christopher Aubrecht, Giulio Iovine, Manuel Pastor, and Denis Cohen. DOI 10.1007/s11069-017-3102-1	Journal article (peer-reviewed)
P12	**Fekete**, Alexander; Tzavella, Katerina; Armas, Iuliana; Binner, Jane; Garschagen, Matthias; Giupponi, Carlo; Mojtahed, Vahid; Pettita, Marcello; Schneiderbauer, Stefan; Serre, Damien (2015) Critical Data Source; Tool or even Infrastructure? Challenges of Geographic Information Systems and Remote Sensing for Disaster Risk Governance. ISPRS Int. J. Geo-Inf. 2015, 4, 1848-1869; DOI: 10.3390/ijgi4041848	Journal article (peer-reviewed)

Table 2 Additional publications relevant for this topic

Nr	Publication	Type
P13	Fekete A (2011) Common Criteria for the Assessment of Critical Infrastructures. Int J Disaster Risk Sci.2:15-24.	Journal article (peer-reviewed)
P14	Fekete A (2012) Spatial disaster vulnerability and risk assessments: challenges in their quality and acceptance. Natural Hazards.61:1161-1178.	Journal article (peer-reviewed)
P15	Stephan C, Norf C, **Fekete** A (2017) How "Sustainable" are Post-disaster Measures? Lessons to Be Learned a Decade After the 2004 Tsunami in the Indian Ocean. Int J Disaster Risk Sci.1-13.	Journal article (peer-reviewed)
P16	Fekete, A. & Hufschmidt, G. (2014) Special Issue on: "The Usefulness of Resilience and Vulnerability for Disaster Risk Management" in: International Journal of Disaster Risk Science.	Special Issue (9 articles, 93 pages, peer-reviewed)
P17	Fekete A, Hufschmidt G (2014) From Application to Evaluation: Addressing the Usefulness of Resilience and Vulnerability. Int J Disaster Risk Sci. 2014/03/01;5:1-2.	Journal editorial
P18	Fekete A, Hufschmidt G editors (2016) Atlas der Verwundbarkeit und	Edited Book

	Resilienz – Pilotausgabe zu Deutschland, Österreich, Liechtenstein und Schweiz; Köln & Bonn | Atlas of Vulnerability and Resilience – Pilot version for Germany, Austria, Liechtenstein and Switzerland. Cologne & Bonn.	(172 pages)
P19	Pigeon, Patrick; **Fekete**, Alexander; Hufschmidt, Gabriele (2017) Book review: "Atlas Vulnerability and Resilience/Atlas Verwundbarkeit und Resilienz", Disaster Prevention and Management: An International Journal, Vol. 26 Issue: 3, pp.377-379, doi: 10.1108/DPM-02-2017-0023	Book review
P20	Fekete, A. (2013) Schlüsselbegriffe im Bevölkerungsschutz zur Untersuchung der Bedeutsamkeit von Infrastrukturen – von Gefährdung und Kritikalität zu Resilienz & persönlichen Infrastrukturen. In: Unger, C. et al. (eds.) Krisenmanagement – Notfallplanung – Bevölkerungsschutz. Festschrift anlässlich 60 Jahre Ausbildung im Bevölkerungsschutz, dargebracht von Partnern, Freunden und Mitarbeitern des Bundesamts für Bevölkerungsschutz und Katastrophenhilfe. Duncker & Humblot, Berlin: 327-340. ISBN 978-3428140770	Book chapter
P21	Hufschmidt, Gabriele; Blank-Gorki, Verena; **Fekete**, Alexander (2016) „Wissen" als Ressource: Bedarfe, Herausforderungen und Möglichkeiten im Bevölkerungsschutz. Notfallvorsorge 3/2016: 19-25.	Journal article (editorship)
P22	Fekete, Alexander & Kraff, Nicolas (2012) Infrastrukturen im Blick. Bedeutung, Trends und Bedrohungen aus Sicht von Branchenexperten. Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, Bonn. Bevölkerungsschutzmagazin, 2/2012: 32-36.	Journal article (editorship)
P23	Fekete, Alexander & Walter, Andre (2011): Risiko- und Krisenmanagement im Bevölkerungsschutz – die Verbindung von Fähigkeiten vor und nach einer Krise. Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, Bonn. Bevölkerungsschutzmagazin, 2/2011: 2-9.	Journal article (editorship)
P24	Fekete, A. (2011): Resilienz: wie widerstands- und anpassungsfähig sind wir? - Die Verbindung von Aspekten des Risiko- und Krisenmanagements im BBK. Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, Bonn. Bevölkerungsschutzmagazin, 2/2011: 20-23.	Journal article (editorship)
P25	Fekete, Alexander & Fiedrich, Frank (Eds.)(2018) Urban Disaster Resilience and Security. Addressing Risks in Societies. The Urban Book Series, Springer. ISBN 978-3-319-68605-9. 518 p.	Edited Book (29 chapters, 70 authors)

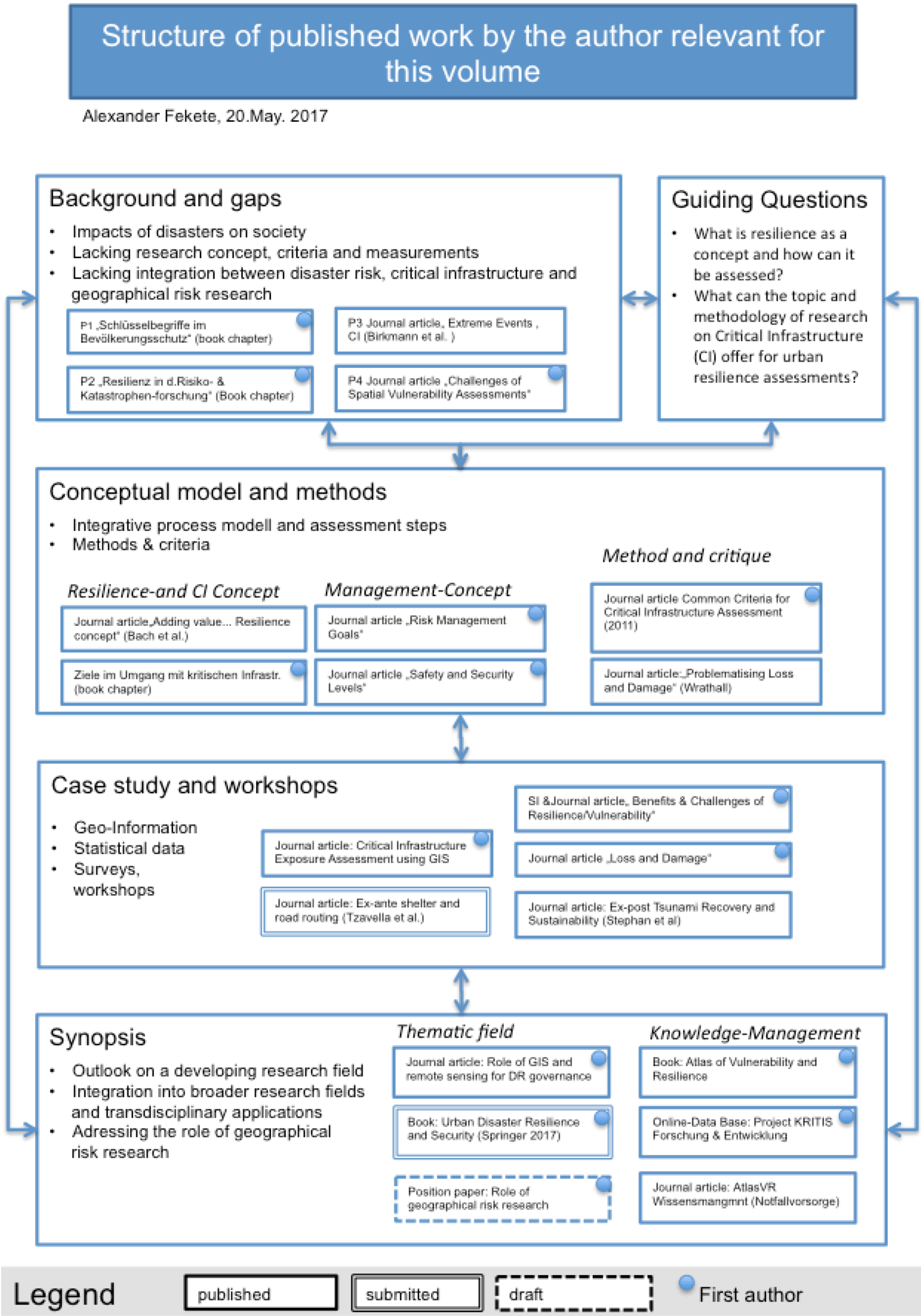


Figure 1 Guiding sheet and structural flow chart of the publications by the author relevant for this volume (Source: author)

1. Problem Statement and Research Questions

Urban areas are population, culture and infrastructure concentration points. Electricity blackouts or interruptions of water supply severely affect people when happening unexpected and at large scale. Interruptions of such infrastructure supply services alone have the potential to trigger crises. But when happening in concert with or as a secondary effect of an earthquake, for example, the crisis situation is often aggravated. This is the case for any country, but it has been observed that even highly industrialised countries face severe risks when their degree of acquired dependency on services of what is termed Critical Infrastructure (CI) (US Government 1996) results in even bigger losses when occurring unexpectedly in a setting that usually has high reliability of services.

Examples for severe societal impacts of CI failure are blackouts (2003 in USA, Italy, 2005 in Germany, Münsterland) or impairment of lifeline services after floods (Germany 2013) or earthquakes disrupting roads, logistics, housing and even administrative infrastructure (Haiti 2010, Nepal 2015, Pakistan 2015). Urban areas or in general, settlements are increasingly prone to adverse effects of CI failures due to an increasing reliance and dependency on the goods and services provided such as electricity, tap water and so forth.

German society, embedded in Europe is vulnerable to infrastructure service interruptions such as water or energy outages and interruptions in transport of goods (European Commission 2008; FMIG - Federal Ministry of the Interior of Germany 2009). While such interruptions can be triggered by natural hazards such as floods and storms, it is also the cascading effects of small technical failures that have the potential to accumulate to major service interruptions. Specifically, in European countries, the effects of river floods triggering power outages have been notable in recent years (Germany, Romania and UK, for instance in 2013-2014). However, IT hacker attacks as well as cooling system failures during summer periods have also caused delays in everyday service functionality. The German rail system lost a major transportation hub, the railway station in Dresden, in the flood 2002 for several weeks; and the main rail connection between Berlin and Hannover in 2013, also due to river-floods, for several months (DKKV 2015). In a large-scale emergency scenario, rail is a major transportation medium for evacuations. Yet not only railways, but also ports are major hubs for logistic chains, and are not independent of major natural hazard events. Also, energy, water and transportation are tightly coupled and failure in one node cascades not only in the very same infrastructure but spills over to affect other CI as well (MSB - Swedish Civil Contingencies Agency 2009; Rinaldi et al. 2001). Finally, government bodies and regulators play pivotal roles in maintaining coordination during crises. They themselves are under threat of (cyber-)attacks, flood events or power failure (US Government 1996).

The detrimental effects on people and institutions in Europe range from individuals affected up to tens of thousands of households without water or other basic services. And this is just one part of the overall society's resilience that can be severely hampered by infrastructure service interruptions. The interruption of airways, rail or roads to deliver emergency services, transplant organs, or allow fire fighters access to burning buildings or power plants is another aspect of disaster resilience that is tightly connected to what is termed 'Critical Infrastructure' (CI). Tight interconnection is also the main key term in describing the opportunities created by modern infrastructure services such as telecommunication or energy distribution. At the same time, this is one of the main vulnerability of modern society. Loss of interconnections needs to be analysed and addressed within disaster resilience. Strengthening CI links and planning for alternatives can be seen as key elements in disaster preparedness and, therefore, need to be a significant component within the resilience architecture of CI.

The problem of the sensitivity of modern society in Europe to Critical Infrastructure failure was acknowledged by the European Commission (EC) in the COUNCIL DIRECTIVE 2008/114/EC of 8 December 2008 'on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection' (European Commission 2008). It is based on a Green Paper from 2005 (European Commission 2005) and suggests risk analyses to be undertaken and criteria to be developed for 'European Critical Infrastructures'. A number of activities and projects have been initiated for this topic of Critical Infrastructure Protection (CIP), and disaster risk management principles have been developed, for instance in the 'Risk Assessment and Mapping Guidelines for Disaster Management' (European Commission 2010). Yet since infrastructure systems are such complex systems and there are numerous sectors of CI that often differ between countries in Europe, and since the interdependencies are numerous, it is still necessary to develop and implement CI concepts and methodologies. And within this complex field, specifically the concept of resilience has gained widespread recognition in many fields of Critical Infrastructure Protection (CIP) (US DHS 2013). However, the benefits and challenges of common terminology, heterogeneity of legal and practical usage between countries in the EU and especially the application of this complex concept with instruments is still a major challenge concerning 'resilience' **(P9)**(Fekete et al. 2014).

Quality and quantity of the detrimental effects of infrastructure failure vary due to spatial context, local setting and situation of the community affected and due to type of stressor. There is a history of such crises and of related research and management (Koski 2011; Fekete et al. 2016) **(P18)**. In the past decades, the term Critical Infrastructure has received a certain attention (Bouchon 2006). While it has become a strong policy and research stream, it is hitherto only loosely connected to other dominating fields such as (natural) Disaster Risk Reduction or Climate Change Adaptation.

Resilience has become a major paradigm in disaster risk research. In the Yokohama strategy (United Nations 1994) resilience appeared only once, even in the review of the strategy in 2005 (United Nations 2005), only twice. Vulnerability, on the other hand, is found in both documents a great number of times. In the Hyogo Framework for Action (UNISDR 2005)and the follow-up recent Sendai Framework for Disaster Risk Reduction (SFDRR) (United Nations 2015) resilience is the predominating term. While it has become almost unavoidable to use it in work on DRR, the methodological application of resilience is fuzzy and often debated (Alexander 2013; Manyena et al. 2011; Manyena 2006). There appears to exist a demand to advance and apply resilience assessments

(Kelman et al. 2016). And while CI is named as an important research and action field in the HFA and SFDRR, applications and combinations with existing risk and vulnerability studies are lacking.

In order to progress in Disaster Risk Research, it is important to improve identification of risk factors. So far, infrastructure is largely not included into traditional risk assessments (Kröger 2008). Critical Infrastructure assessments however offer important methodological elements to advance risk assessments (Yusta et al. 2011; Bara and Brönnimann 2011); for instance, a better strategic underpinning and formulation of the goal of the assessment by linking the assessment to human needs and services offered by infrastructure. Second, CI adds criticality assessment to traditional methods looking at risk as probability or combination of hazard and vulnerability.

But also the traditional assessment of CI in its own field needs improvement, which can easily be offered by a geographical perspective. It is necessary to advance infrastructure assessments by applying them in geographical regions other than just analysing critical elements and nodes without spatial context.

The improvement of the methodology of CI risk assessment helps to improve risk identification and therefore enables better monitoring and decision-making to mitigate hazards and risks associated with CI, especially, CI failure.

Problem fields in summary

The following problem fields are hypothesised in order to explain the scope of this study.

Societally, and ***normatively***, there is a demand to understand processes and effects of hazards and disasters better in order to mitigate negative effects on society (HFA, SFDRR).

Academically, there is a gap in connecting knowledge acquired in the field of natural hazards and what is termed Disaster Risk Reduction with human crisis research that includes technical infrastructure failures but also intentional destruction such as wars.

Conceptually, there exist desiderata in these academic communities but also increasingly amongst security and safety professions and related governmental institutions to make more use of the concept of resilience and make it applicable.

Methodologically, there is still a lack of applicable (also termed: operationalisable) criteria and related semi-quantitatively measurements of resilience.

Among ***case-study*** selections, the current focus of integrative societal resilience studies is mainly either on large cities or on smaller communities. Middle-size cities however, receive relatively fewer attention within the research on so-called 'resilient cities' or 'urban resilient' so far.

Regarding the state of the art in research, the focus is beyond pure hazard and damage assessments. The resilience perspective is more about recovery and persistence of the system impacted by the hazards. This study draws upon topics currently eminent within the resilient cities theme (UNISDR 2012), and standardisation of methodology debate and development (Fritzsche et al. 2014).

Research Intention

This study emphasises a specific research field, the case study serves only to demonstrate to indicate application opportunities of resilience. The term 'operationalisation' is used in order to cover applications of resilience, in terms of putting-it-in practice by analysing (semi-quantitatively 'measuring') it. Main objective of this study is to contribute to knowledge advancement on the methodology and concept of CI assessments. Urban areas are one context, but in fact the scope of CI rather combines urban and rural areas than limiting itself to urban areas only.
The role of Geography as a broad holistic discipline is discussed in this study in relation to risk research as an equally holistic however multi-disciplinary field. There are mutual benefits from both the discipline of Geography and the risk research field that go beyond traditional hazard and location assessments, or traditional urban anthropological studies. The study wants to indicate the potential for interdisciplinary integration between physical and human Geography as well.

The following key research questions are conceptualised after what Richard Feynman defined as the core content of science: a) contributing to the body of knowledge, b) techniques and applications and c) innovations (modified after (Feynman 2007).

Body of Knowledge

1. What is resilience as a concept and how can it be assessed?
2. What is the resilience of a specific region and how can this be assessed?

Techniques and applications

3. Which techniques such as methods of risk and resilience assessment can help to better understand urban disaster resilience?
4. How can resilience be assessed in a case study?

Innovations

5. What is the novelty of urban resilience versus pre-existing concepts of disaster protection or sustainability?
6. What can the topic and methodology of research on Critical Infrastructure (CI) offer for urban resilience assessments?

2. State of the art in the fields of urban resilience and critical infrastructure

The etymology of the word "resilience" is the Latin verb "resilire" meaning to rebound. According to the Merriam Webster dictionary Resilience is commonly defined as "the capability of a strained body to recover its size and shape after deformation caused especially by compressive stress". The IPCC and UNISDR define resilience as:

> "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions".

As pointed out first by Holling (Holling, 1973) and then (Holling and Meffe, 1996; Holling, 1987, 1978) the concept of resilience is closely related to equilibrium analysis of a complex adaptive system. Or in other words, resilience refers to the stability of current state and speed of returning to that state (Berkes and Folke, 1998). There are several elements that produce a feedback to the system and hence makes it relatively adaptable to stressors (Pendall et al., 2009). Resilience therefore captures ex-ante and ex-post activities and processes of a system. Resilience also points to the characteristics of a system to thrive despite adversity (Pendall et al., 2009). (Foster, 1997) interprets resilience in terms of coping with contingencies. It is also about non-linearities in an uncertain environment. In this view, a disturbance can flip a system from one equilibrium to another (Berkes and Folke, 1998). This understanding of resilience can also be contrasted to high systemic vulnerability (interdependencies between physical, economic and social systems)(Adger, 2006, 2000). Despite its generic character, resilience is path dependent (Redding, 2002), therefore certain aspects are related to the system analysed or to specific hazard contexts. While vulnerability is much focused on static assessments of status-quo weaknesses of a system (Adger 2006), resilience is more about the dynamics of a system and its recovery (Nelson et al., 2007; Paton and Johnston, 2006). Yet, just as vulnerability, the resilience of a of a system is multidimensional (Yates and Sanjeevi, 2012).

Treating resilience from a disaster and risk perspective, it offers to regard 1. the ability to control the states of the system by improving its resilience, and 2. to reduce the effect of the threat (Haimes, 2006). As with risk, hazard and vulnerability, some authors emphasise the basic question of "resilience of what, to what?" (Walker, 2002). Meanwhile, there are myriads of application field for resilience, and some claim resilience to regard society as a whole (Cavalieri et al., 2012), or damage to buildings (Jenkins et al., 2014) or to economic, social or agronomic processes (Wilson et al., 2012).

Some researchers summarise the characteristics of resilience as being diverse, renewable, functionally redundant, with reserve capacity achieved through duplication, interchangeability, and interconnections, efficient, autonomous, adaptable, collaborative (Rose , 2004; Foster, 1997; Godschalk, 2003; Rose and Krausmann, 2013; Rose, 2007). Constraints in applying resilience in policy fields of risk management for example, lie in a lack of clear mandates, guidelines and cooperations in resilience, yet (Molin Valdes et al., 2012).

2.1 Resilience and vulnerability as predominant concurrent concepts in disaster risk and security research

The Hyogo Framework for Action (UNISDR 2005) is an internationally recognized key document promoting the application of concepts and methods of achieving resilience and vulnerability in the context of natural hazard impacts. The first phase of the Hyogo Framework for Action (HFA) ran from 2005-2015, and has been evaluated, for instance, at the Geneva global platform for DRR, May 2013. Amongst many different DRM and CCA concepts, the HFA evaluation process has led to scrutinise how resilience and vulnerability have been put into action, and to critically analyse the benefits and pitfalls of these concepts and their application in practice. The Sendai Framework for Disaster Risk Reduction (SFDRR) is the follow-up strategy for the years 2015-2030 that

incorporates lessons-learned from the HFA. Resilience is the key overall paradigm and vulnerability assessments are still promoted, infrastructure assessments emphasized.
Resilience and vulnerability have also been key concepts in the realm of climate change adaptation research in the recent past (Manyena 2006). There exist major conceptual overlaps and a great number of documents analyse the interrelations of climate change to expectations of recent or future disaster impacts (IPCC 2012). In the climate change community, the concepts of resilience and vulnerability (R&V) and their applications in practice are increasingly questioned and challenged by alternative ideas and models. Recently, some researchers have explored alternative concepts, such as loss and damage measurements, in order to provide incentives for the troubled international climate change negations of the IPCC (Wrathall et al. 2015; Fekete and Sakdapolrak 2014) **(P8, P7)**. Now, many scientists who are purveyors of the resilience and vulnerability paradigm must return to long-abandoned concepts in order to propel delicate negotiations and debates in the international community forward. However, the vagueness of R&V, as compared to the more easily observed facts of loss and damage, have encouraged scholars and practitioners to put R&V to the test.
Some countries, like Germany, have been eager to explore the benefits of R&V for national civil protection schemes of late also (Workshop in Berlin 17-18. Feb. 2013 by acatech, Fraunhofer and Forum Öffentliche Sicherheit on resilience; Fekete and Hufschmidt 2014) **(P16, P17)**.

In order to assess and document the state of the art of resilience and vulnerability, we have conducted a number of activities, including workshops, surveys and publications. During a symposium organised by the "Katastrophennetzwerk KatNet, a German disaster network (15.-16.Nov. 2012 in Bonn, Germany) the topic "Resilience and Vulnerability was discussed: What is the usefulness of these concepts for disaster risk management?" In oral presentations and world café groups 86 participants debated on the relevance and anticipated impacts of upcoming concepts of resilience and vulnerability. Discussion partners were persons from various backgrounds, mostly academic but also representatives from national and municipal administration, police, fire brigade and industry. The main outcome of the workshop was the confirmation that in Germany, terms and concepts such as vulnerability and resilience are still largely unknown or lacking application in a civil protection context. After the workshop a survey was conducted, in order to elicit and document main constraints in adoption of these concepts so far and 38 attendees of the symposium responded. Some selected presentations of the workshop were published afterwards in a special issue (Fekete & Hufschmidt 2014) as were the results of the discussion and the survey (Fekete et al. 2014). The results of the survey show that main benefits of adopting the terms resilience or vulnerability were seen in a conceptual advancement (Figure 2) beyond existing defence or risk frameworks and agendas. Measurability, on the other hand, was mentioned to a much lesser extent; especially for resilience there appears to exist a demand for further applications.

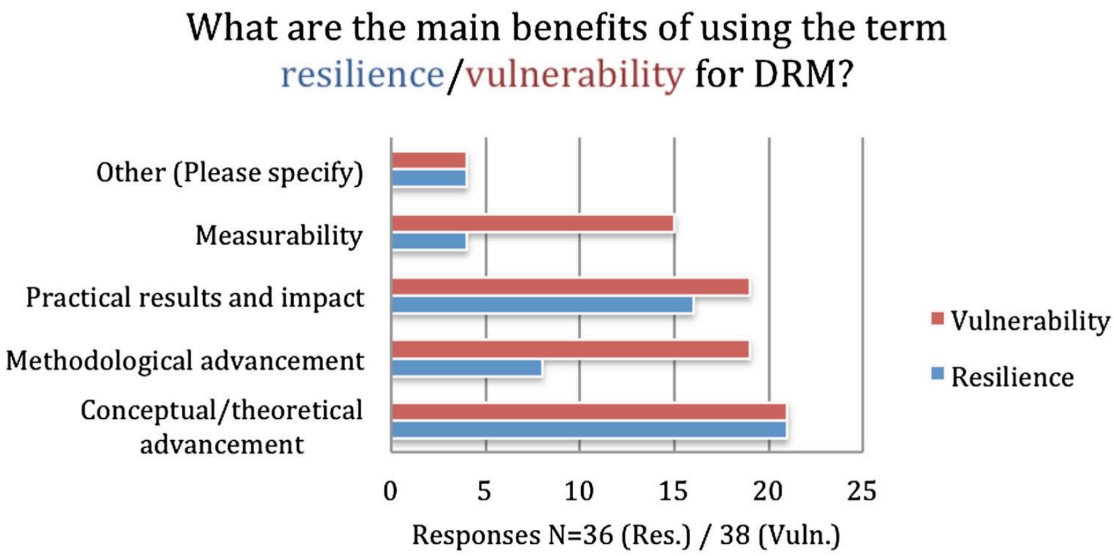


Figure 2 Survey results for the question after the main benefits of using the terms resilience and vulnerability (Source: Fekete, Hufschmidt, Kruse 2014: 12) (P9)

Many challenges hindering applications of resilience or vulnerability were mentioned according to definitions of those terms, but also application and putting-it-in practice and measuring it (operationalisation) (Figure 3). Challenges of unwanted resilience (that means, unintended forms of resilience such as terrorists' capabilities) or side-lining of existing concepts such as risk or hazard were not regarded as problematic as possible misuse in general.

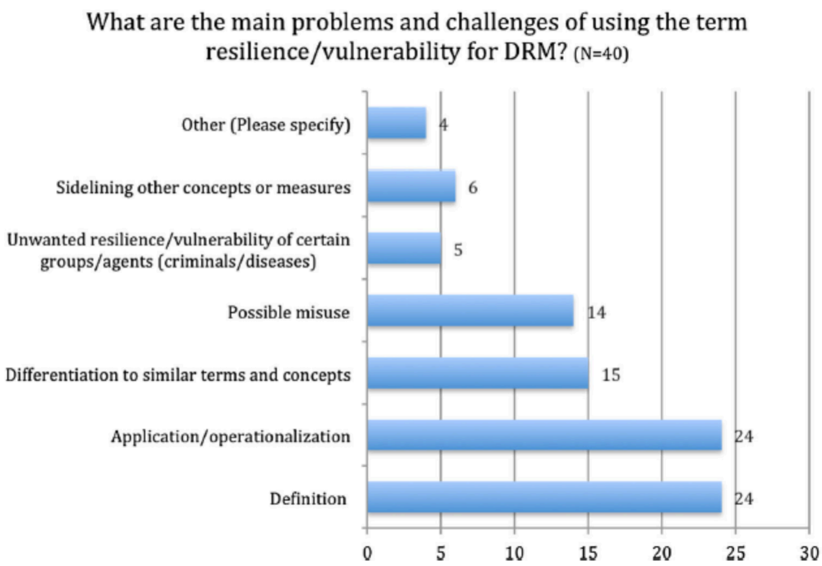


Figure 3 Survey results for the question after the main problems and challenges of dealing with resilience and vulnerability as a term (Source: Fekete et al 2014: 13) (P9)

However, this small survey is certainly not just limited in regard to number of respondents, but is also biased due to the input the participants were exposed to during the symposium and workshop. Nevertheless, this symposium and survey highlight certain perceptions of the concepts of resilience and vulnerability that were prevalent also in other communities of academics as well as practitioners at that time.

At international level, another trend topic discussion was observable in context to the IPCC negotiations – some developing countries expressed frustration about lack of progress in climate negotiations and brought an alternative concept to the table; loss and damage (Wrathall, et al. 2015) **(P8)**. This was certainly a surprise for all those pushing ex-ante concepts such as prevention and preparedness, including many aspects of how resilience, vulnerability and risk are mainly framed. The need to focus on losses and damages was based on the need to document impacts of climate change and natural disasters more clearly. It also reflected a long lingering uncertainty and lack of robust documentation concerning the questions if and how prevention and preparedness can be measured, can be proved effective. While more and more reports were published that try to prove how many dollars are saved by dollars invested in prevention such as the Stern Report (Stern 2006), the need to also focus on immediate losses and damages certainly had a basis. In order not to just push the resilience agenda in our work in a myopic way, but also to be reflective of the paradigms behind, a survey was conducted on how practitioners and experts in the field of civil protection view loss and damage as an alternative to resilience and DRM. 40 responses to this survey were received, and it must be stated that it were mainly German respondents, the same as had been asked after the symposium mentioned above. These respondents were mainly uninformed about the international developments of the "loss & damage" debate. Therefore, it was especially interesting to reveal if they would regard loss & damage as viable alternatives to resilience or vulnerability in DRM contexts. The survey results show a heterogeneous picture and loss & damage is just one among many other concepts or agendas popular in 2014 (Fekete and Sakdapolrak 2014) **(P7)** (Figure 4). Adaptation and sustainability are dominant concepts, especially in a German context. But also robustness was mentioned more often than loss & damage. Under the category 'other' (Figure 4) terms were mentioned such as coping or adaptive capacity, risk, threat etc.

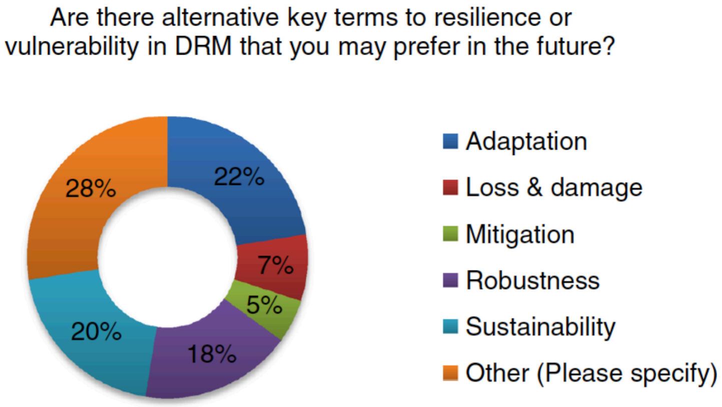


Figure 4 Reponses to the question on alternative terms to resilience and vulnerability (N=30, Source taken from: Fekete & Sakdapolrak 2014: Int J Disaster Risk Sci (2014) 5:88–93: 89) (P7)

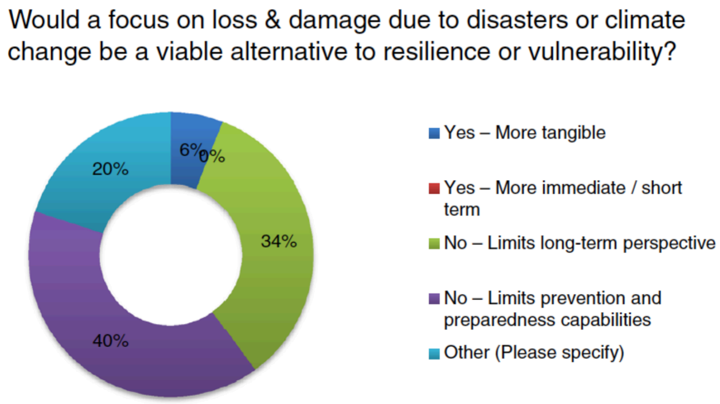


Figure 5 Reponses to the question on loss & damage being an alternative to resilience and vulnerability (N=38, Source taken from: Fekete & Sakdapolrak 2014: Int J Disaster Risk Sci (2014) 5:88–93: 89) (P7)

In the other question, whether a shift of focus to loss & damage could be an alternative (Figure 5), disagreement prevailed. Reasons to be sceptic about such a shift of focus include that it could limit the long-term perspective of DRM and efforts on prevention and preparedness. However, one methodological limitation certainly is that the options for answers were predefined, in order to direct the respondents, while there also was an open answer field. Tensions between short- and long-term perspectives are typical in DRM and in German civil protection at national level, for example, a division of risk management (ex- ante, long-term) from crisis management (short term, after the impact) can be observed (Fekete and Walter 2011) **(P23)**.

As another result, an "Atlas of Vulnerability and Resilience" was compiled (Fekete & Hufschmidt 2016) that provides an overview on the state of the art in resilience and vulnerability assessments in German-speaking countries. At the same time, the Atlas is as a book, online PDF and website a knowledge management platform and also be a mediator between science and practice in civil protection. The Atlas contains 10 short overview chapters on key conceptions of resilience and vulnerability in different disciplinary contexts such as community resilience, critical infrastructure, urban areas or psychology. The purpose is to combine an overview on all interest fields in DRR or civil protection and foster learning by diversity. For example, people already versed in one concept can detect how resilience is conceptualised differently in another field and be inspired from this what to add to their own area.

Figure 6 Atlas of Vulnerability and Resilience title page and example of case study sheet (P18)

The Atlas VR also contains 45 case studies, also in short overviews (Figure 6) from different backgrounds such as public administration, industry, but of course, also academia. The Atlas VR is a Pilot version for Germany, Austria, Liechtenstein and Switzerland and in order to foster cross-cultural understanding, is published in two languages that allow accessibility by the readers in German language but also allow for direct comparison of how the terms are used in English. Additional criteria allow for direct identification of methods, data used and can serve for future studies aiming at validation studies, state-of-the art overviews or longitudinal studies. Overall, the Atlas VR provides a tool for recent identification of risk-contexts and knowledge management. It ties in with demands at international level, for example, priority 1 in the Sendai framework for disaster risk reduction (UN 2015).

The recent prevalence of discussions about the topic of resilience provides an impetus to critically review this issue using different perspectives in order to obtain innovative results. New concepts at the heart of resilience theory push beyond the 'resistance, robustness, and return-to-the-previous-state' mind-set, also include perspectives on alternative futures and transformations that will modify and force the further development of human mind-sets and systems.

Resilience is the new key term in many national governmental strategies for risk reduction, Critical Infrastructure, and emergency management. Despite the widespread use of the term resilience, there is a burgeoning debate about how the popularity of the term represents new innovation in the fields of Disaster Risk Management (DRM) and Climate Change Adaptation (CCA) (Fekete and Hufschmidt 2014; Glavovic and Smith 2014; Hudson-Doyle and Johnston 2011) **(P1, P7, P8, P17, P24)**. Some of these debates include the limitations of resilience as a bouncing back concept (Levine 2012), unwanted resilience of malevolent networks (Zolli and Healy 2012). However, while the state-of-the-art of this field becomes established (US NRC – National Research Council 2012), critique on the concept is growing (Deeming 2013) and stimulates critical scientific work on both benefits and challenges.

Likewise, the term sustainability represents a major paradigmatic impulse that is forcing the fields of DRM and CCA to move beyond short-term solutions, one-sided benefits and identifying limited geographical impacts of risks (Aitsi-Selmi et al. 2015). The present discussion of disaster, risk, climate change and critical infrastructure illustrates the importance of complex adaptive systems research for these fields, and shows the manner in which it has actively pushed the search for long-term solutions while considering the dynamics of risk and risk measures at the same time. Furthermore, this burgeoning area of investigation explores interdependencies and global repercussions of local disaster events, and the risk-related countermeasures and stakeholders involved.

2.2 Resilience of settlements and resilient cities as a specific research topic

Resilience of settlements and resilient cities are prominent in contemporary disaster risk and systemic change research, policy and funding (Vale and Campanella 2005; Coaffee and Lee 2016; Pelling 2003; The World Bank 2012; Serre et al. 2013). Reports and analyses on the Nepal earthquake 2015, Hurricane Sandy in the USA 2012, the multiple events in Japan 2011, the Christchurch Earthquakes of 2011, Haiti Earthquake in 2010, or numerous other disasters that received worldwide public attention, are being investigated both with regards to pre-disaster resilience levels and post-disaster integration of resilience into recovery strategies. Terrorism, especially after 9-11 is another direction and driver of this topic (Godschalk 2003). This effort aligns with other endeavours such as 'Making Cities Resilient' (UNISDR 2012), a campaign endorsed at international level, yet targeting local decision-makers (Johnson and Blackburn 2014). Many other institutions devote themselves to the topic of resilience, often with an urban focus, such as UNISDR, UN-Habitat (for example, the 2016 conference), United Cites and Local Governments, (UCLG), ICLEI-Local Governments for Sustainability (ICLEI), the European Commission Community Humanitarian Office (ECHO), the World Bank, the International Institute for Environment and Development (IIED), The Rockefeller Foundation through the creation of the 100 Resilient Cities Network, and many others. Urban resilience has also become a topic for urban planning worldwide, as can be seen as a topic for UNHABITAT, where urbanization processes, vulnerable groups and infrastructure have long been relevant key words already (UN/HABITAT 2002), but where recently, for example at the latest world conference in Quito 2016 in the 'new urban agenda' (UN/HABITAT 2016a), resilience has become an explicit component, yet is integrated with other topics such as sustainability (for example , the Sustainable Development Goals of the UN), green economy, insecurity or urban density (UN/HABITAT 2016b).

2.3 Critical Infrastructure Protection and Resilience

Urbanity, settlements and infrastructure are among the most important aspects of modern civilisation (Ferguson 2011). Infrastructure per se has a long tradition in urban studies, and some parts of it are also recognised as 'built environment', a field where resilience is also an upcoming topic (Hassler and Kohler 2014). Critical Infrastructure protection is another area receiving practical and academic attention of late (Koski 2011), which is also strongly related to DRM and CCA, but also to a broader security context (Collier and Lakoff 2008). It covers natural hazards, climate and other types of change, while expanding the focus to technical and human-induced crises and disasters as well. Initiated by bomb attacks on critical infrastructure in the U.S. in the 1990s (World Trade Center bombing, Oklahoma City Bombing of the Alfred P. Murrah Federal Building), the U.S. government started a major program that heavily transformed U.S. security policy and institutions (US Government 1996). This program also exerted significant influence over European policy and institutions (European Commission 2008) and national civil security debates, contingencies and emergency management, as well as over DRM practice in local and regional public institutions and the private sector. The technical advancement of the Internet, an increasingly globalised interrelationship and dependency on resources of all kinds, and the 2001 terrorist attacks in the U.S., sparked the emergence of novel topics in the field of DRM, IT and cyber security, protection of resources and infrastructure.

Table 3 Critical infrastructure sectors in Germany (Source: www.kritis.bund.de, accessed 10.3.2016)

Critical Infrastructures	
• Energy • Information technology and telecommunications • Health • Water • Food	• Transport and traffic • Finance and insurance industry • Government & public administration • Media and culture

Table 4 Department of Homeland Security: Critical Infrastructure Sectors[1]

Sectors
• Chemical Sector • Commercial Facilities Sector • Communications Sector • Critical Manufacturing Sector • Dams Sector • Defense Industrial Base Sector • Emergency Services Sector • Energy Sector • Financial Services Sector • Food and Agriculture Sector • Government Facilities Sector • Healthcare and Public Health Sector • Information Technology Sector • Nuclear Reactors, Materials, and Waste Sector

1 Source: https://www.dhs.gov/critical-infrastructure-sectors , accessed on 18.05.2017.

2 For project KritisFuE, see an English summary in https://riskncrisis.wordpress.com/research-projects/kritisfe/, and the final report (in German) here: http://www.bbk.bund.de/SharedDocs/Downloads/BBK/DE/FIS/DownloadsInformationsangebote/DownloadsKritische

- Transportation Systems Sector
- Water and Wastewater Systems Sector

Resilience and vulnerability concepts have had a major impact in the field of Critical Infrastructure protection also (Boin and McConnell 2007). While some countries have long adopted both, in recent years a strong paradigm shift away from risk to a resilience perspective can be observed (Australian Government 2010; UK Cabinet Office 2008; Rogers 2011; US NRC – National Research Council 2012).

The provision of electricity and water services are major basic needs of modern societies (FMIG - Federal Ministry of the Interior of Germany 2009). These infrastructures, termed "Critical Infrastructures" and identified by certain sectors that differ in parts between Germany (Table 3) and USA (Table 4) are at the same time vulnerable but also interdependent. Disruptions of the infrastructure services e.g. by natural hazards or man-made failures can cause damages in multidimensional ways and affect large parts of the population and industry (FMIG - Federal Ministry of the Interior of Germany 2011).

Electric energy and water are among the key infrastructure services (see Tables 3 and 4) and stand out due to a high degree of criticality as their incapacitation or destruction would have a severe effect on (economic) security and public health or safety. The indisputability of their importance have become apparent in recent power outages and water shortages in many world regions, like Hurricane Sandy in the US or the consequences of the Tsunami in Fukushima, but also at French coasts and during river floods in Germany (in 2002 and 2013).

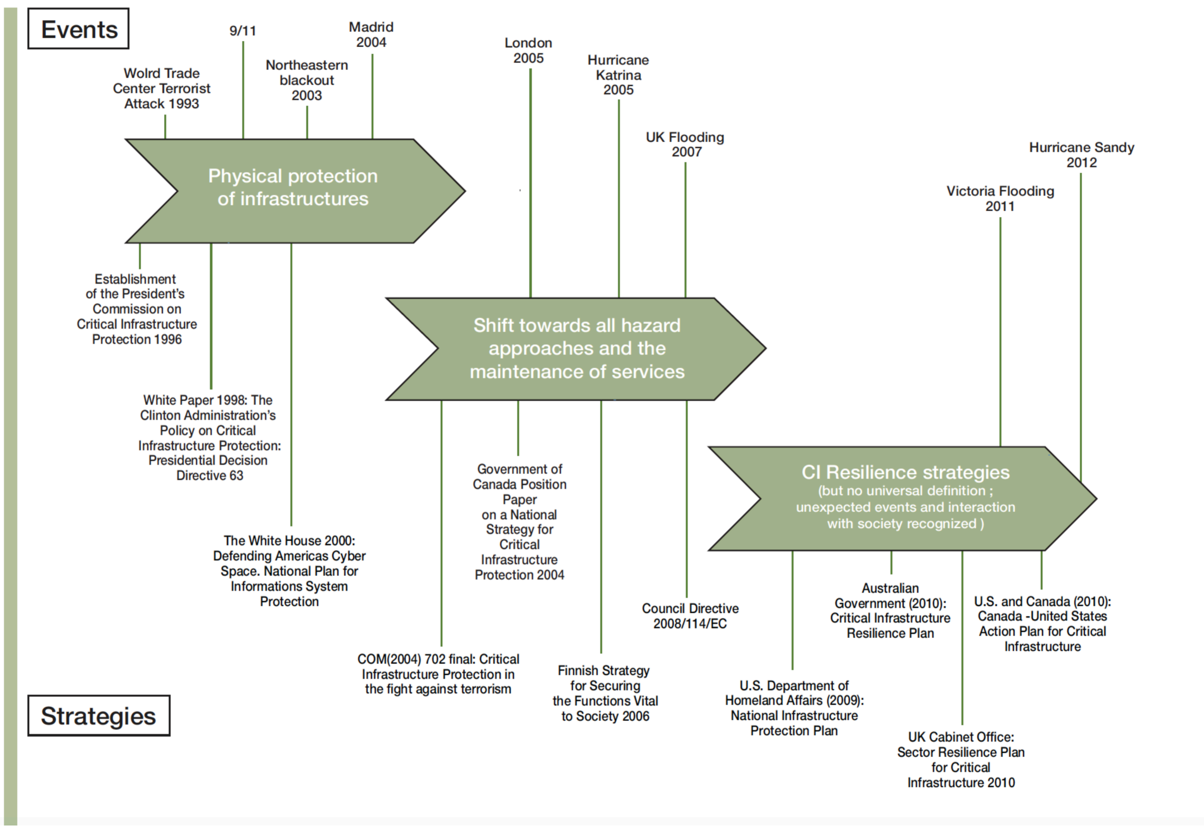


Figure 7 Development of resilience strategies in the wake of disastrous events (Bach et al. 2013)
(P4)

An even greater concern exists for large local or regional failures of infrastructure supply, due to human or technical failures or severe weather conditions, with possible cascading effects throughout Europe. Several cases of power outages in US or Europe in 2003 for instance, or, the 2005 Münsterland outage in Germany following a snow storm, all triggered political and academic activities in the field of CIP (FMIG - Federal Ministry of the Interior of Germany 2011). Figure 7 shows how CI events and regulations following such events also influenced policy developments in context to resilience in the field security. The effects of cross-national interdependence have been shown in events like the 2003 blackout in Canada and USA caused by high temperatures or the 2006 blackout in Europe caused by planned disconnection of a high voltage line in Emsland, Germany (UCTE – Union for the Co-ordination of transmission of electricity 2007).

In order to build up Critical Infrastructure resilience, not only the vulnerabilities of a certain Critical Infrastructure have to be regarded. It is the interconnected characteristics of CI systems that have to be taken into account (Rinaldi, et al. 2001; Bach, et al. 2013). Drinking water supply for example directly depends on the provision of electricity e.g. for the operation of pumps (O´Rourke 2007). Equally, electric power supply may be disturbed in various ways by water infrastructure, for example through pipe bursts or abrupt demand changes by water works and pumps being major electricity consumers. New challenges for Critical Infrastructures arise from new political and economic developments on national and European level. Increasing decentralization and privatization of energy infrastructures in line with the advancement of renewable energies and smart grid systems in Germany as well as changes on European water markets are examples for growing interdependencies and challenges. Furthermore, the increasing interconnectedness with IT infrastructures is a development pervading most Critical Infrastructure sectors (European Commission 2013).

These changes have consequences not only on the functioning of Critical Infrastructures but they change the methods as well as practical requirements of crisis management and security strategies at the same time. Decentralized insular energy producers such as households or small enterprises might for example have less resources and knowledge on maintaining IT security measures necessary in the decentralized systems or conducting risk analyses (Bach et al. submitted 2014: 19).

Parallel to increasing interdependencies between Critical Infrastructures, reforms in the energy market as well as climate change will possibly also affect CIs, as the dependency on environmental services (e.g. water supply, resources for renewable energies) will be growing (Marshall 2013). Moreover, as water and electricity supply sectors are characterized by the provision of services through private operators, a large group of stakeholder with a wide range of interests and expertise is involved (FMIG - Federal Ministry of the Interior of Germany 2011). Therefore, the state not only has to merge these interests and expertise in a coherent way but also has to acknowledge that its potential to directly address and influence disaster risk related aspects of service supply is limited (Fekete et al. 2012) **(P6)**. It has to be kept in mind that in the case of a disastrous event a variety of private and public actors in the field of civil protection will have to cooperate and align their responsibilities and actions under time pressure.

In order to establish an overview on the state of the art in research on Critical Infrastructure of relevance for civil protection in Germany, a research project called KritisFuE (Critical Infrastructure Research and Development) carried out in 2013 by our institute helped to document and structure existing research in this field. An online data base was developed, with more than 90 national and international studies and research projects on the CIP topic were analysed regarding their relevance to civil protection using standardised criteria. The results were summarised in two-pager overview sheets containing key information such as project run-time, partners, goal and methods. This database is online and openly accessible[2].

Main findings of chapter 2 - 'State of the art in the fields of urban resilience and critical infrastructure'

Chapter 2 provides findings mainly attributed to the research questions:

Body of Knowledge

1. What is resilience as a concept and how can it be assessed?
2. What is the resilience of a specific region and how can this be assessed?

Innovations

5. What is the novelty of urban resilience versus pre-existing concepts of disaster protection or sustainability?
6. What can the topic and methodology of research on Critical Infrastructure (CI) offer for urban resilience assessments?

-> Q1. An abundance of work exists on what resilience is conceptually, and this is different according to each disciplinary background, be it the usage and emergence of resilience within ecosystem research, psychology, engineering or other origin **(P16)**. In context to Disaster Risk Research, resilience is conceptually well documented and defined for instance, by UNISDR, however, many researchers demand for more applications of resilience, for example, within assessments in case studies. While vulnerability is used in certain strategic EU and UN documents rather for risk assessment methods, resilience is widely used as an umbrella term, partly replacing risk **(P16)**.

A terminological basis is provided for clarifying the usages and differences of terms such as criticality and vulnerability and risk in context to German civil protection terminology and concepts **(P20)**. Concurrent usage and upcoming

[2] For project KritisFuE, see an English summary in https://riskncrisis.wordpress.com/research-projects/kritisfe/, and the final report (in German) here: http://www.bbk.bund.de/SharedDocs/Downloads/BBK/DE/FIS/DownloadsInformationsangebote/DownloadsKritische Infrastrukturen/DownloadMethodischerTeil.pdf?__blob=publicationFile
The summary sheets, sorted according to the German national CIP sectors, can be found here: http://www.bbk.bund.de/DE/Service/Fachinformationsstelle/Informationsangebote/Forschungsberichte/ForschungKritischeInfrastrukturen/ForschungKritischeInfrastrukturen_node.html

fields of application of the term resilience in context to civil protection and civil security research and policy in Germany is explained **(P1)**. Insights are offered into why German research and practice in the field of civil protection is lagging behind international research for reasons of translation and pre-existing aspects such as participation and bottom-up responsibility the resilience paradigm is driving especially in English-speaking contexts.
The book 'Urban Disaster Resilience and Security' **(P25)** will summarise international research on how resilience can be operationalised. in different disciplines that all are however, related to security and risk. A preliminary finding is the continuing existence of academic struggle in conceptualising resilience first, before in can be measured or put into practices. The book provides opposing views and opinions regarding measurability of resilience, bottom-up versus top-down approaches, quantitative versus qualitative assessment methods. In certain case studies, resilience is found to be helpful by introducing a more holistic perspective and offering incentives for better integration of stakeholders. Some other chapters are more critical about this and warn about uncritical and top-down application of concepts working in one country transferred to other countries.

-> Q2. The Atlas of Vulnerability and Resilience **(P18)** provides a first overview on case studies operationalising resilience and vulnerability in context to man-made and natural hazards and risks in German-speaking countries. The work on the Atlas revealed gaps in knowledge about concepts, methods and data types and evaluation studies. It also revealed a much more general and widely shared problem; knowledge management on disaster risk and civil protection topics is mostly lacking amongst stakeholders in academia, governmental organisations and industry alike. The Atlas VR fills a gap in data and method documentation, sharing and awareness raising on networks but also gaps in knowledge management.

-> Q5. Regarding the field of **resilience in context to disaster risk**, the main findings are that while both vulnerability and resilience are popular topics within disaster risk research there exist different maturity and acceptance levels in different countries **(P16)**. Due to language, for example, German-speaking countries are lagging behind Anglo-American countries in using the concept of resilience. Reasons for adopting those concepts range from science trend and funding opportunities to expectations of new methodological input. Consequently, innovations in those areas of risk assessment first need to be aware about the motivations for adopting resilience (or not) and secondly, be aware about different interests and phases of adoption of the term.

-> Q6. It is shown that both CI and urban disaster resilience are tightly intertwined and that conceptually it is feasible and an existing gap to operationalise it, hence conduct integrative assessments **(P3)**. Within a special issue on resilient cities, findings include an urgency to advance research and disaster risk management practice on the topic and concept of resilience **(P4)**. The paper highlights importance and ways of better communication between stakeholders and system characteristics such as scale effects that need to be considered.

3. Gaps in current research and practice

3.1 Conceptual gaps

There is ample documentation for cities at risk (Joffe et al. 2013), and documentation about recovery of cities (Haas et al. 1977). For the urban resilience topic, especially more research on recovery is needed (Contreras Mojica 2015; Davis and Alexander 2015). But there is a lack of holistic analytic concepts and tools for 'disaster resilient societies' that integrate the technical perspectives of CI technical structures and processes with the fields of human error, organisational management and corporate culture, effects on society and the vulnerabilities and dependencies of societies on the daily functioning of CI services (Christmann et al. 2016). Moreover, there is a lack of longitudinal studies on recovery and lessons to be learned studies after global (academic) attention ceases (Stephan et al. 2017).

Critical infrastructures are highly complex systems of systems. They combine old and new technologies, are determined by human behaviour, underlie compound economic considerations, and are framed by different organisation types and regulations (Utne et al. 2008). The complexity of systems, operating settings and impacts has increased constantly. For instance, as smaller systems are more and more integrated into larger systems (particularly due to modern ICT). Moreover, the risks these systems have to face become increasingly complex and are loaded with ever-larger uncertainties (e.g. due to newly emerging hazards as a consequence of climate change or international terrorism). Societies therefore have been and will continue to be confronted by ever-larger challenges for assessing risks in the context of CIs. Existing processes to assess and reduce the consequences of CI failures have, due to this, often proven to be inadequate (Kröger 2008). 'Classical' risk analysis approaches based on methods such as fault and event tree methodology, are not able to grasp the high complexity and interconnectedness of these 'system of systems'. Moreover, they have to build on assumptions such as the independence from contextual factors, the fail to address dynamic and non-linear behaviour of systems and, most importantly, human or societal factors can and are thereby not sufficiently taken into account (Kröger 2008: 1786).

There is a lack of holistic concepts and tools for Disaster Resilient Societies that integrate the technical aspects of CIs and its processes with the fields of human error, organisational management and corporate culture, effects on society and the vulnerabilities and dependencies of societies on the daily functioning of CI services.

Despite of the relevance of addressing societal aspects in combination with bio-physical and technical factors, more holistic assessments which are able to consider the interconnectivities of systems across different dimensions are still rare (Kahan et al. 2009). The European directive on CI (European Commission 2008) has, for instance, no concrete guidelines on how to link society and critical infrastructure in risk assessments more coherently (Atzl and Keller 2013).

Especially in the fields of DRM with a background in technical and structural assessments has been recently advanced into a more holistic 'all-hazard' and 'whole-of-nation" approach, for instance, within US homeland security after 9-11 but also in countries such as UK within their resilience registers and the EU within their CIP activities (see Fekete et al 2014 for an overview) for identifying cross-sectoral and sectoral indicators of CI importance and failure impacts. This is a scientifically as well as politically and technically striving field, where engineering criteria meet social criteria (Bruneau et al. 2003) and connect the technical / structural world with what is called 'community resilience' approaches so far known from a more development background (Edwards 2009).

However, the complex character of impacts, particularly due to cascading effects, has made it to a topic rarely addressed and lacking conceptual clarity (Pescaroli and Alexander 2016). The IPCC (2012: 412) SREX report states, for instance, that "only a handful of studies have investigated the wider macroeconomic consequences of impacts or adaptation". A failure in any CI leads with a high probability to impacts on most parts of society. These impacts emerge and act across sectoral, temporal and administrative borders. An assessment of these cascading effects therefore also needs a cross-sectoral perspective on multiple temporal, administrative and spatial scales.
Taking a cross-sectoral perspective is essential for assessing cascading impacts and risks. The wide-ranging impacts across all sectors due to the eruption of the Eyjafjallajökull volcano in Iceland in April 2010 has imposingly shown the criticality arising from inter-sector dependencies (Lewis et al. 2013). Nevertheless, almost no cross-sector studies have analysed those cumulative effects (IPCC 2012: 412).

3.2 Gaps in Methods and Measurements

The topic of CI is currently still separated from DRR and CCA research in many respects. The integration of these fields may enable the embedding of criticality assessments into holistic risk, vulnerability and resilience assessments as well as their frameworks, which would thereby advance methodology and comprehensiveness of the assessments. This is not to say that this is novel in principle; criticality had been part of the earliest systemic risk assessment methodologies, for example, of the earliest risk matrices (US DoD - United States Department of Defense 1980) and precursors of this military standard dating back to the 1940s However, in prevailing vulnerability indices and resilience literature within natural hazards research, criticality is rarely integrated. This study wishes to meet the demand formulated by the Hyogo Framework For Action (UNISDR 2005) and recently, the Sendai Framework for Disaster Risk Reduction 2015-2030 (WCDRR - World Conference on Disaster Risk Reduction 2015) to assess and integrate infrastructure risks, recognising their importance for societies' resilience concerning natural hazards impacts. At the same time this meets desiderata in the Critical Infrastructure, Disaster Risk Reduction and Climate Change Adaptation communities to advance resilience from concept to measurement and operationalisation (Roege et al. 2014).
One major challenge is to obtain resilience concepts suitable for application. Another challenge is to obtain data, which is especially the case for ‚critical' infrastructure often being related to ‚critical' i.e. for sensitive data (Fekete et al. 2015) **(P12)**.

Another aspect impairing operationalization is the lack of simple, feasible and standardized criticality analyses that do not overburden time and other resources of decision-makers experts and scientists alike (Theoharidou et al. 2009). Responsible for this is not only the complexity of CI systems themselves but also ambiguities between the key terms risk, vulnerability, resilience, and criticality (Fekete 2011) **(P13, P20, P24)**.

Main findings of chapter 3 'Gaps in Current Research and Practice'

Body of Knowledge

1. What is resilience as a concept and how can it be assessed?

Techniques and applications

3. Which techniques such as methods of risk and resilience assessment can help to better understand urban disaster resilience?

Innovations

6. What can the topic and methodology of research on Critical Infrastructure (CI) offer for urban resilience assessments?

-> Q1. Methodologies and research frameworks exist in a DRR context that can in principle be used and advanced by applying them in urban contexts adding CI and expanding them on resilience aspects **(P3, P14)**. However, key challenges of working with risk assessment methodologies remain, for example key limitations of methodology such as lacking stepwise procedures how to grasp and then analyse resilience, but also hindrances in user acceptance and it outlines how previous mistakes could be avoided.

Differences between terms such as vulnerability and criticality are observable **(P20)** and point at an on-going development in the field of risk analysis, where a gap exists in integration of fields such as natural hazards, disaster risk reduction and critical infrastructure protection.

Challenges and shortcomings of certain semi-quantitative vulnerability indicator assessments exist **(P14)** by failing to integrate into a more comprehensive risk framework such as risk management, but also by failing to find acceptance amongst users, partly due to methodology, visualisation and misunderstandings, but also due to different usages and misuses by different stakeholders that had not been involved; affected people and decision-makers.

-> Q3 & Q6. In the fields of critical infrastructure in context to disaster risk, a main finding is that Critical Infrastructure is a topic still largely unconnected to traditional DRR or CCA research (P13). The short review on how and in which fields the topic of critical infrastructure evolved and spread also points at different threat contexts and language barriers, but also disciplinary misunderstandings of the topic being mainly technical and not also, of societal importance. International research in context to the Sendai Framework for

Disaster Risk Reduction views extreme events as an opportunity to advance understanding on Climate Change effects in context to disaster risk management (P3). For urban planning specifically, human vulnerability and critical infrastructure should be further integrated into existing spatial planning but also disaster management. Lacks of applications of CI analyses are identified **(P20)**, as well as deficits of applications of both urban disaster resilience and CIR studies and combinations of them, especially **(P1, P3)**.

4. Conceptual Model and Methods Used in This Study

This volume utilises a conceptual model covering all three phases of the so-called disaster cycle, i.e. the ex-ante, immediate and ex-post phase of a disaster. The case studies in this volume cover those three phases. Figure 8 shows a model of the disaster cycle that was developed to suit to the work of the German Federal Office of Civil Protection and Disaster Assistance in combining the two worlds of crisis and risk management, which represent measures and management philosophy of the Federal Office divided into reactive phase (crisis) and preventive phase (risk).

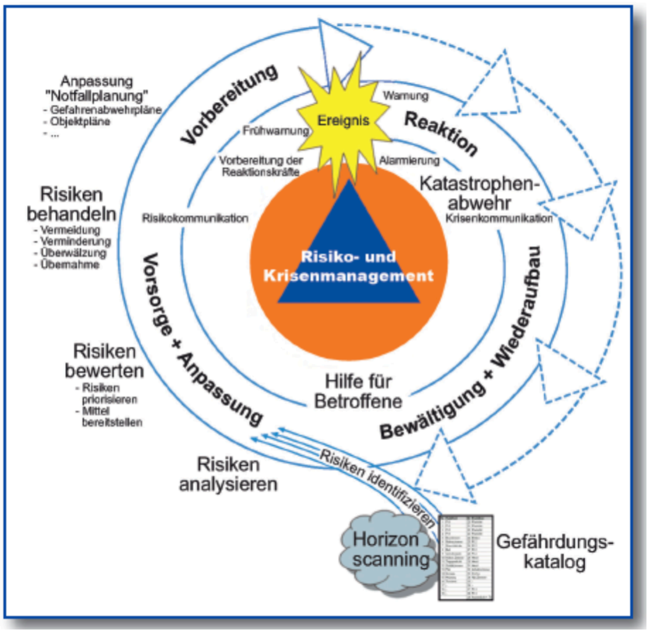


Figure 8 Risk and crisis management disaster time phase cycle in German national civil protection (Fekete and Walter 2011) (P23)

In this volume, we start with an ex-post assessment case study, which lays the foundation of development of criticality criteria for application in ex-ante predictions of future events, since the overall conceptual goal is to better handle future disasters by building upon knowledge from past experience. Another goal is to contribute to the improvement and amendments of exiting RMKM and CI concepts and methods. This work therefore conforms to existing conceptual models of disaster phases and according research and management steps. Figure 9 shows the risk management project process cycle, condensed and fitted to the model used in this work, and derived from the work with ISO 31000 (ISO - International Organization for Standardization 2009) and the risk management guideline for risk management of critical infrastructure (FMIG 2011) that itself is based upon precursors of the ISO 31000, the NZ/AUS 2004 (Australian/New Zealand Standard 2004).

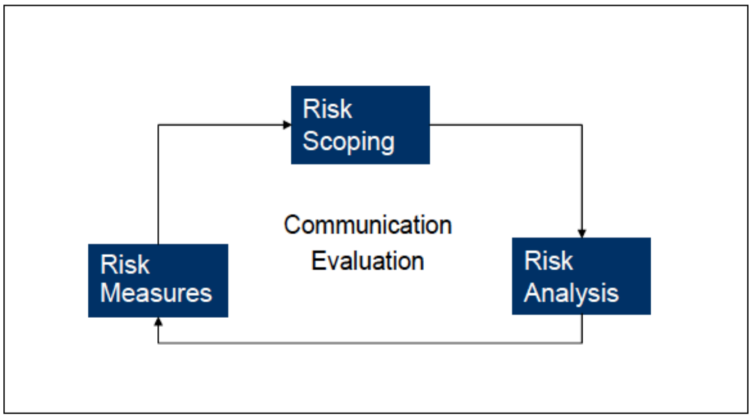


Figure 9 The risk management project process cycle in modified version (Fekete, et al. 2012) (P6)

4.1 Phenomenon context: Natural and man-made risks in a disaster risk management paradigm

This study embarks on phenomena of both natural and human origin and their modifications of 'nature' and 'environment'. Daily occurrences and standard emergencies are not in the focus, but rare and unusual events that carry the potential to cause widespread destruction, loss of human lives and damages to economy, the political system and social order and wellbeing. While most research in the risk and security community, but also in Geography is strictly split between either natural or man-made processes, this work integrates both types. While there is a plethora of debates and terminology disputes about content and delineation of key terms such as "natural" or "risk", at this stage such discussion should not be repeated or be perpetuated but rather refer to reviews and overviews on this aspect (Felgentreff and Glade 2008; Porfiriev 1998) and suggest a salomonic simplification. Figure 10 shows the schematic division of the hazard/threat side of phenomena (causes) and the impact side (effects). The specific aspect of Critical Infrastructures is their intermediate stance as aggravating impact effects due to their high level of interconnections with all types of impact layers.

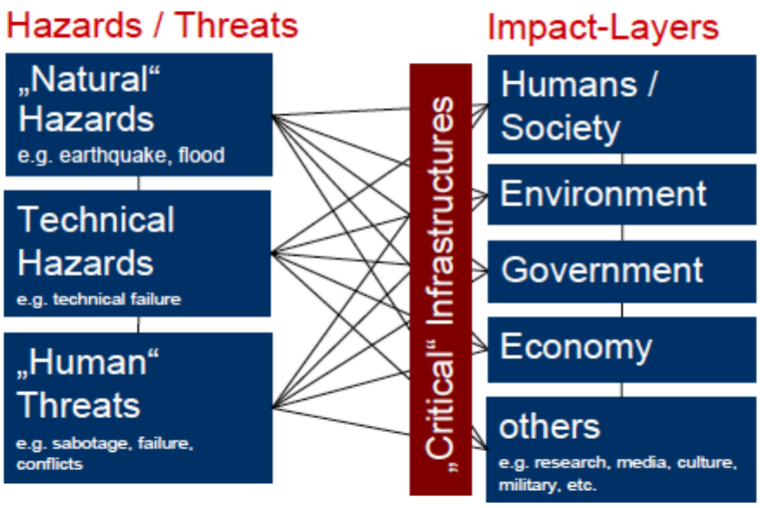


Figure 10 Multiple hazards and threats on the left side and interdependencies with multiple impact layers on the right side (in: Fekete, Lauwe, Geier 2012 Int. J. Critical Infrastructures, Vol. 8, No. 4, 2012: 339) (P6)

Interdependencies between hazards, Critical Infrastructure and society are an important strand of research in CI (MSB - Swedish Civil Contingencies Agency 2009; Rose 2007; Rinaldi, et al. 2001). While many quantitative and qualitative approaches are sought after and tested, it still remains a hugely complex task to analyse all interdependencies of human settlements with electricity only, but interdependencies between water, energy, IT, transport and others grow this complexity furthermore. This study uses a schematic model to differentiate the multiple impact reaction chains. While in most studies, interdependencies are only analysed for the inter-CI relationships, the following figure (Figure 11) shows that there exist interdependencies already between hazards and their effects, otherwise known as secondary hazards. Infrastructure components impacted by hazard events then develop interdependent cascading effects. However, cascade strictly speaking is not accurate enough since not just linear stepwise reactions may follow but also star-shaped or cloud-type of reactions can emerge in distributed networks or amongst decentralised agents. Finally, the population is included in this model that included effects not just of the initial impacts but of all intermediate process paths and, of course, interdependencies between populations, since no human population is homogeneous in demography, ambitions, spatial and cultural setting.

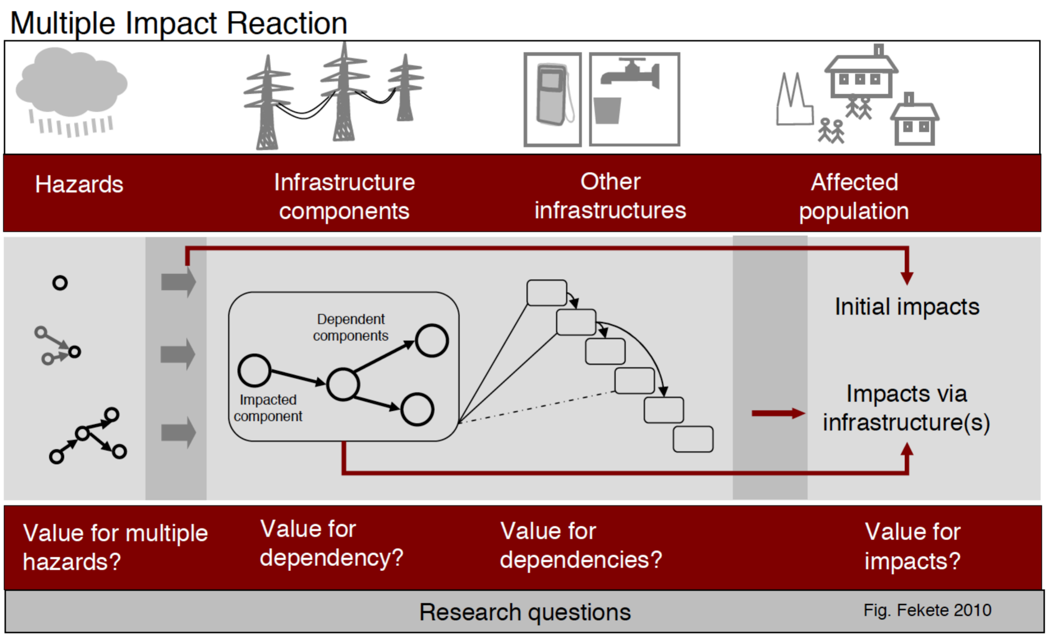


Figure 11 Schematic illustration of different phases of hazards impact chains and interdependency reactions (Source: author)

4.2 Risk handling paradigm

This study uses the term and concept of disaster risk management (DRM) in a version that integrates bottom-up with top-down approaches and puts communication not at the end of a process but acknowledges its role throughout the process, as has been emphasised in the risk governance model (IRGC - International Risk Governance Council 2008). However, to clarify terminology, there appears to exist a rather unreflected paradigm of Disaster Risk Reduction as well as usage of the term management. Both terms imply a normative decision that disaster risk must necessarily be reduced or that risk must and can be managed or governed. While this might be the proper approach in many cases, there is some reflection necessary that risk avoidance and creation of a 100% secure and risk-free society not just might create other risks but is also just unrealistic. It surprisingly sidelines well established other aspects of risk handling and action such as shifting risks, or risk acceptance (Fekete, et al. 2014) **(P9)**. Table 5 illustrates just a few of these important connotations. Similar is true for the concept of resilience which also needs to be accompanied by a scientific reflection also of its downsides or unintended side-effects.

Table 5 Risk handling types, from control over management to tolerating risks (Fekete 2012: 69) (P5)

Terms that express belief in risk control	More passive terminology
• Control • Govern • Increase (capacities, resilience) • Manage • Prevent (hazards and threats) • Protect • Reduce (impacts, risks, uncertainty, vulnerabilities) • Secure • Strengthen • Sustain	• Accept • Adapt • Be flexible • Live with risk • Tolerate

4.3 Resilience

The **concept of resilience** provides an appropriate framing for conceptualising not only cross-scale, -border and -sectoral interactions but provides **more flexibility than common** CI protection (CIP) approaches (Landstedt and Holmström 2007). There are many interlocking influences of resilience from different origins and disciplines such as ecology, engineering sciences, psychology etc. (Fekete and Hufschmidt 2014; Alexander 2013; Lorenz 2013). Apart from a system understanding there are other conceptions of resilience such as a human capitals understanding of resilience (Edwards 2009) which is often applied in so-termed community resilience approaches (Maguire and Cartwright 2008) or psychological conceptions of resilience, or behavioural and risk perception studies. In this volume, disaster resilience is understood as to what extent and degree systems recover from a disaster and reach a new state of existence (UNISDR 2009; Gallopín 2006; Folke 2006; Holling 1973a).

Typical for resilience concepts, especially those referring to system dynamics, is the temporal dimension and process fluctuation as depicted in Figure 12. Any type of object or system moving along the path receive an external impact or their internal modification prompts decline and back-swing. Future states are unknown but may include full recovery (bounce-back) or to a lesser or higher level than before (including string modifications or adaptations).

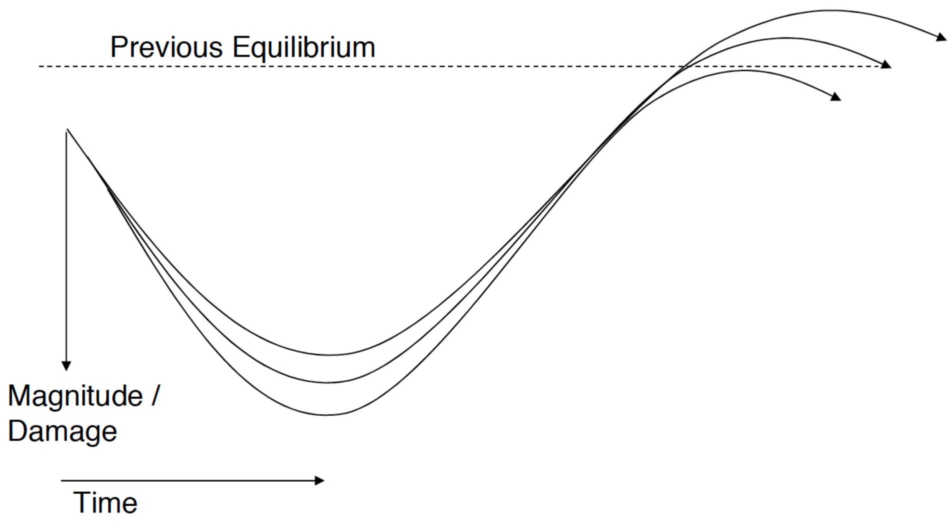


Figure 12 System or object process path (Source: author)

This study regards resilience to be composed of three conceptual resilience categories (Maguire and Cartwright 2008): **Persistence** of a system (see also equilibrium models, future pathways, etc. in for example (Holling 1973b), (Gunderson and Holling 2002)); **recovery** (also termed 'bouncing back' (Maguire and Cartwright 2008; Zolli and Healy 2012) and **transformation** (also termed change, adaptive capacity, bouncing forward, see for instance (Pelling 2011).

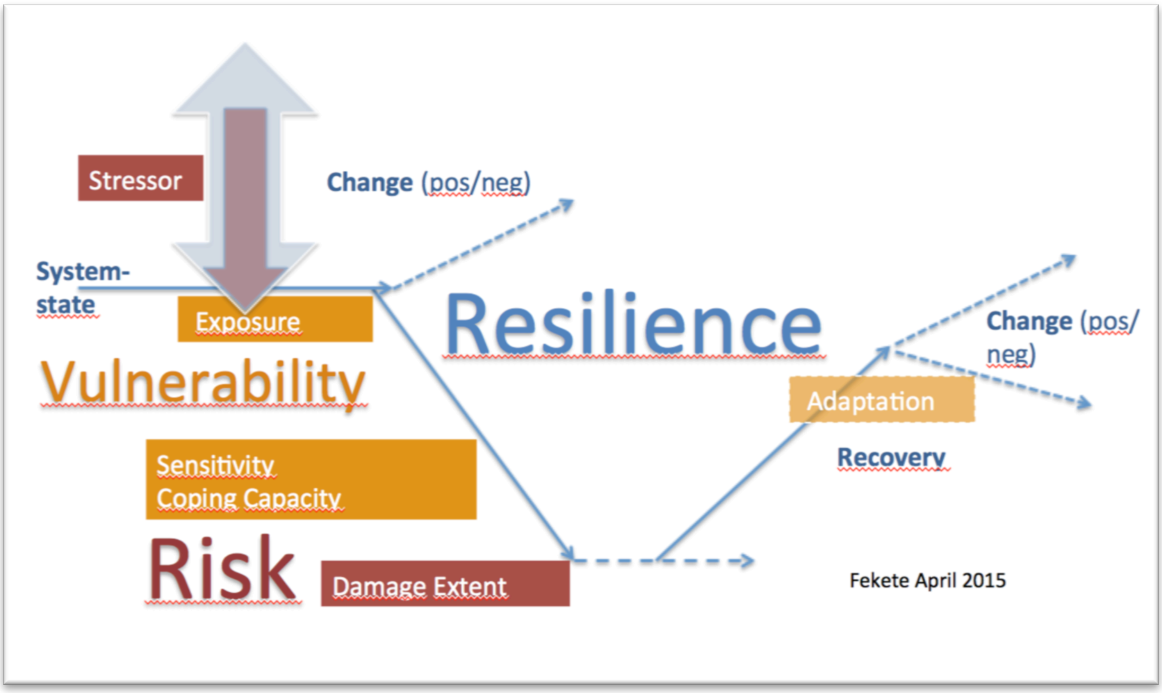


Figure 13 Resilience Process Model (Source: author)

Figure 13 displays the resilience conceptual understanding used in this study. It represents a two-dimensional 'elasticity' model of a given system, in this case, Critical Infrastructure or city population. This system receives attention as a possible target by its presence and importance. This presence or importance is directly related to its criticality; it is critical for both sides – inhabitants and attacker. Then, certain hazard-attraction points such as Critical Infrastructure nodes, hubs or connections are attacked. The system degrades in a balance between impact stress and resistance resources available. There is a turning point after which the system stabilises and then recovers. Factors for this turning and recovery include buffers (or 'cushions'), recovery resources and also development-attraction factors. The system may then return back to the previous state, or may not achieve it, and it may transform. While this two-dimensional 'elasticity model' is not adequate to represent reality and complexity in many respects, it is widely in use (HS SAI - Homeland Security Studies and Analysis Institute 2010) and simplifies the overall process. This allows breaking resilience down into entities that can be represented by indicators. The pitfalls of representing complexity by simplification are not discussed here, nor the shortcomings of indicators in representing reality, given that this has been all well-documented (de Sherbinin 2014; King 2001; Hinkel 2011) and not the main focus of this study. The author is also fully aware of the downsides of a linear representation of resilience. This study follows the semi-quantification approaches common in risk or vulnerability assessments applying indicators. Figure 13 shows how resilience factors can be conceptualised that might later on be developed to resilience indicators. Figure 13 also shows how to possibly differentiate vulnerability, risk and resilience factors, while acknowledging that a purely analytical separation is hardly possible. For a discussion on characteristics and also shortcomings of such indicators, see our previous work (Fekete

2012b). This study will use a simplified and reduced set of indicators in order to demonstrate the general usability of data and resilience phases. The author of this volume is also aware of alternative views on such indicators for community resilience (Maguire and Cartwright 2008). However, in this volume, the '4R' model is followed that connects engineering and social aspects (Bruneau, et al. 2003), in order to put the focus here on conceptual consistency rather than on completeness of all factors necessary to explain the resilience model in figure 13 or in general.

Bruneau et al (2003) provide a comprehensive analysis of natural hazard loss reduction under the heading of resilience. They assert that resilience has four dimensions, which are listed below:

- „Robustness: strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function
- Redundancy: the extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality
- Resourcefulness: the capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis; resourcefulness can be further conceptualized as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals
- Rapidity: the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption“

4.4 Criticality

There are several **definitions of Critical Infrastructures (CI)** proposed by different legislative institutions. The **definition of CI** from the European legislative context of Article 2 of Directive 2008/114/EC defines Critical Infrastructure as:

"asset, system or part thereof ... which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact as a result of the failure to maintain those functions".

Criticality is the importance, or more specifically vitalness, of a given element for humans or society. This is a generalisation of common definitions of criticality in CIP, for instance for the purpose of national civil protection (FMIG - Federal Ministry of the Interior of Germany 2009). Criticality is also the state of a system reaching a point of change (crisis) that may turn out either positively (critical mass used in nuclear reactions to make them work) or negatively (critical state of an overheated oven) (see (Fekete 2011) **(P13)**. Infrastructure in this sense is the sum of all natural and man-made structures and their elements, including the people who maintain them.

4.5 Infrastructure

Especially within Critical Infrastructure Protection (CIP) and resilience communities, this work aims to advance the perspective of a Critical Infrastructure by extending the existing technical perspective of the criticality of its components onto the impacted customers – the people. Current natural disaster risk reduction research allows for a more integrated assessment of technical as well as human factors. For instance, such concepts of an integrated risk management or risk governance (ISO - International Organization for Standardization 2009), (IRGC - International Risk Governance Council

2008) embrace multiple levels of stakeholders while CIP research and policy typically focuses on operators and regulatory bodies. Another advancement pursued by this work is to expand the notion of what Critical Infrastructure is. In the perspective of this work, CI is vital for society and is an integrated part of society. CI includes technical as well as man-made assets, but also includes the social and environmental context. Social environment sets the frame of CI providers and customers. Natural infrastructure includes key ecosystem services such as water and food but also includes the most basic of survival needs and basic infrastructure – ground, ground stability, soil, topography and geographic setting in general. In this volume, it is hypothesised that natural infrastructure in concert with man-made infrastructure and their related services are vital for human individual and societal survivability - exemplified at the level of cities in this work.
Research units of Critical Infrastructure in this approach include more types than usual studies that only include physical and technical elements and processes. In this study, also the environment and humans are regarded as part of the overall CI system (Table 6).

Table 6 Infrastructure components (Fekete 2011: 17, P13**)**

Technical structures/ assets	**Human staff**	**Functions**	**Environment**
Nodes Linear or network structures	Staff in: Planning Management Maintenance Repair	Organisation Processes Quality Regulations	Environmental services Natural resources Spatial setting

4.6 Research area

As research object and unit, settlement areas have been selected because of the density of human lives, properties and density of Critical Infrastructure. This corresponds to major research streams in DRR and related resilience, wherein the impacts of hazards on society are currently researched under what is termed "resilient cities" and "community resilience" (see previous chapters).
As a research context, the spatial research area of Germany has been selected. The administrative scale has been selected for reasons of political applications in decision making of the outcomes of such assessments. Another reason is the range of regulations, cultural context, economic and other societal factors that are not limited to, but still largely influenced by national boundaries.

4.7 Criticality assessment

A criticality assessment is similar in principle to risk assessments. Criticality assessments are either about the importance of certain elements for the overall system or express the impacts on society, on a mission or company. But in context to CI, some aspects are characteristic, such as:

„There are at least three ways to describe criticality:
(1) Criticality might be described by regarding the internal relevance of an infrastructure, in short the maximum

loss of service capability possible. This is the internal system capability;
(2) Alternatively, the external impacts can be described, for example, the number of customers supplied; and
(3) Criticality can also be described by the decisive capabilities needed to prevent, mitigate, or compensate for failures due to infrastructure impairment, for instance the 4Rs of resilience: robustness, redundancies, resourcefulness, and rapidity of Tierney and Bruneau (2007).“
(Fekete 2011: 17) **(P13)**

The German risk management approach on analysing risks of CI is quite peculiar, since it adopts criticality assessment as a prior step to hazard, vulnerability and risk assessment (BMI 2011). The intention is to prioritise and therefore limit the range of analysis to make it more effective. Within research project KritisKAT, in-depth investigations of common features and distinct features of criticality assessment has been undertaken and criteria suitable to identify criticality of infrastructure amongst all sectors and branches in Germany have been identified (Fekete 2011). It was found that despite the variations in approaches for criticality assessments and types of elements and effects of CI and their impairments, three common criteria can be identified:

- Critical proportion
- Critical time
- Critical quality

(Fekete 2011: 18) **(P13)**

Examples, how these common criteria may be developed to analyse CI more specific are provided in Table 7 below.

Table 7 Generic criteria for Critical Infrastructure identification (Fekete 2011: 20) (P13)

Generic criterion	Examples of specific criteria	Examples of applications (many criteria are valid for almost all types of infrastructure)
Critical proportion	Load, capacity, power, sales, turnover, etc.	Traffic, logistics chains, power installed
	Number of assets, nodes, interdependencies, redundancies, emergency capacities	Backup systems for power or information storage; emergency power
	Amount of customers supplied	For instance, the number of people supplied with drinking water
	Outreach / spatial interconnectedness	The single chemical plant in the world producing a key product
Critical time	Failure duration	Air traffic grounding due to volcanic ash
	Mean time to repair, replace, restore the functionality	Replacement time for a transformer station
	Mean time to react	Police, fire brigade, medical units, media, early warning, crisis management
	Timing of failure	Coldest winter day; annual meeting of company leaders; day of distribution of welfare or pay checks
Critical quality	Product or service quality	Water or food quality, trust in finance, training of staff, feeling of security
	Cultural or societal significance	National cultural icons

4.8 A concept for merging technical systems and humans in criticality assessment of infrastructures (Three indirect impact layers of infrastructure failure)

While there is a big discussion about frameworks, concepts and theoretical background in the fields of, for example vulnerability science (Birkmann 2013; Füssel 2007; Bohle 2007), there is still a need to develop such frameworks in criticality assessments (Theoharidou et al. 2009). A conceptual framework for criticality assessment should point out the different dimensions to be considered or measured, for example criticality criteria. Criticality criteria are reviewed and summarised in some sources (Theoharidou et al. 2009), and for specific aspects such as interdependency dimensions (Porcellinis et al. 2009; Rinaldi, et al. 2001). However, an explicit layout and structured concept for aspects specific for criticality assessment of infrastructures is wanting. One major aspect of infrastructure criticality is the indirect impact of a threat or hazardous event on the customers or population. The initial casualties or losses due to an event such as an earthquake are not considered, except maybe for buildings collapsing. The real interest lies in losses due to the failure of infrastructures. This should be depicted in a framework as well as the different layers of impact. The conceptual framework of three impact layers (Figure 14) shows that the initial impact regarded is on a specific infrastructure, and more specifically, on its components. On this first layer of impact it is analysed whether or not a failure of some of the components (including processes or quality aspects) causes an impact on the population (Figure 14, layer 3a). The second layer of impact is where other infrastructures are affected by the failure or impairment of the initial infrastructure on layer one (layer 3b). Their respective failure might also affect the population, which is analysed on impact layer three (3c).

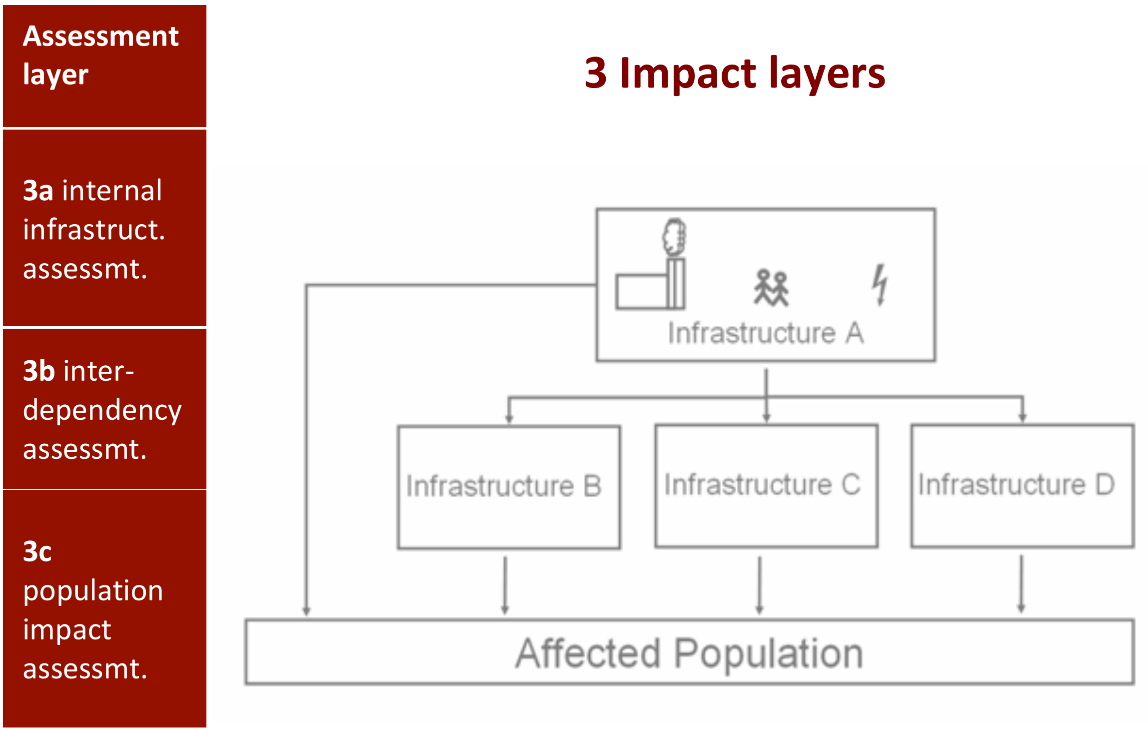


Figure 14 The 3 Impact layers (3Il) framework (Source: author)

Application of the concept

Typically, many criticality analyses focus on an internal view on one specific infrastructure (Figure 14, layer 3a) on whether the infrastructure as a whole fails to function. This approach can also be named internal system analysis or criticality of nodes, of risk elements or internal processes. Some criticality analyses consider interdependencies (layer 3b) to be important, focusing on the links between infrastructures (Robert et al. 2003; Rinaldi, et al. 2001; Robert 2004; Bouchon 2006). However, despite the availability of highly sophisticated modelling of interdependencies, such models are not commonly applied for civil protection purposes. Ultimately, the focus for civil protection and societal risk perspectives is on the impacts on humans (layer 3c). How many people are dependent on infrastructure xyz? This interest should be more explicitly emphasised for civil protection research on infrastructures - instead of focusing on technical system properties.

Regarding the situation from a federal state level for civil protection strategic planning, the critical number of residents for a given city or area of interest could be estimated using the critical amount of capacities for emergency energy supply. The criterion critical timing helps to find a threshold, for example, how long electricity interruption can be tolerated by the residents or how long emergency power can be supplied. Critical timing could also contain the time of the day, month or season an outage would affect residents. The criterion critical quality could be used to describe a crisis that amounts not due to easily measurable items such as number of people or duration, but 'soft' and often 'intangible' issues such as outrage in the population due to a number of previous similar incidents, or the quality of the event which is perceived as unprecedented. The latter example is also known as the 'vulnerability paradox'; "The more a country's susceptibility to failures regarding supply services decreases, the more severe will be the impact of an actual disruptive incident." (Geier 2006; FMIG - Federal Ministry of the Interior of Germany 2009).

Practical considerations such as availability of information often limit capturing criteria. As with many conceptual (meta-) frameworks, explicit advice on weighting or aggregation of single elements or layers is lacking. Furthermore, no selection of methods or analysis procedure is laid out. This allows for the application of different methods or procedures of analysis. The main focus of this framework (Figure 14) is to explicitly outline the indirect impacts on the population of a criticality assessment of infrastructures and to show that the 3CC meta-criteria help to identify the key aspects of criticality on all three layers. The three impact layer (3Il) concept explicitly outlines the different impact layers through infrastructure failures as they subsequently affect the population. It contains important characteristics which differentiate the criticality concept from other risk and vulnerability concepts.

4.9 Conceptual resilience components useful for the analysis of critical infrastructure

While resilience is academically intensively debated about what it means and which aspects it should include or not (see previous chapters and our own findings (e.g. **P1, P3, P4, P7, P9, P12, P16, P25**) the following sub-chapter will try to **conceptually operationalise** resilience. The objective is to narrow resilience down into specific components so that it can be assessed in a place-based risk assessment (following in the next chapter – the **case-based operationalisation**).

Differentiation of vulnerability and resilience components in context to place-based assessments of Critical Infrastructure

In applying the suggested conceptual separation of resilience (Figure 13) from risk, hazard and vulnerability components already used in existing risk assessment models, it is of importance to differentiate vulnerability and resilience, specifically. The reason for this are large overlaps that can be observed between vulnerability and resilience (Cutter et al. 2008). In a number of frameworks, resilience is a sub-component of vulnerability (Turner et al. 2003, FMIG 2011).

The definitions by UNISDR (accessed 19.5.2017)

Resilience

„The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.
30 Aug 2007"

Vulnerability

„The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

Annotation: For positive factors which increase the ability of people to cope with hazards, see also the definitions of "Capacity" and "Coping capacity".
30 Aug 2007"

Exposure

„The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Annotation: Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.
23 Jan 2009"

Since we aim for semi-quantitative assessments, these definitions seem to fit to certain existing risk formulas used within place-based approaches (e.g. Cutter et al. 2008). In some of them, exposure is part of vulnerability, in some it is not and we follow the formulas, which we have applied in previous work in order to enable consistency. The following Figure 15 illustrates how vulnerability and resilience factors could be analysed in a city and separated. Figure 15 displays the surroundings of the city of Cologne during a flood scenario and highlights exposed electricity grid elements in red colour. Within a vulnerability perspective, or as parts of a vulnerability indicator, the exposure to the river-flood would be analysed, for instance, by assessing flooded infrastructure or people living in exposed buildings. Susceptibility could be assessed either of the technical structures or by the characteristics of people affected. The capacities of wither technical or non-structural elements of the electricity grid, for example, or, of the customers and users of electricity could be added to complement the risk index.

What is resilience in such an equation? Either, it is also part of what is already covered by susceptibilities or, specifically, capacities. Or, resilience needs to be separated. Resilience could be analysed by factors such as stability, recovery or transformation aspects, when following suggestions by other frameworks and studies (for instance, Bruenau et al. 2003, Turner et al. 2003). Within an aggregated risk index, it will be important that no confounding overlaps exist, which typically are already a problem in separating susceptibility from capacities (Fekete 2012B) **(P14)**. However, analysing a factor such as 'Mean Time To Repair' as an aspect of resilience and being aware not to duplicate this under 'capacities' allows for later combination of vulnerability and resilience factors in a risk index.

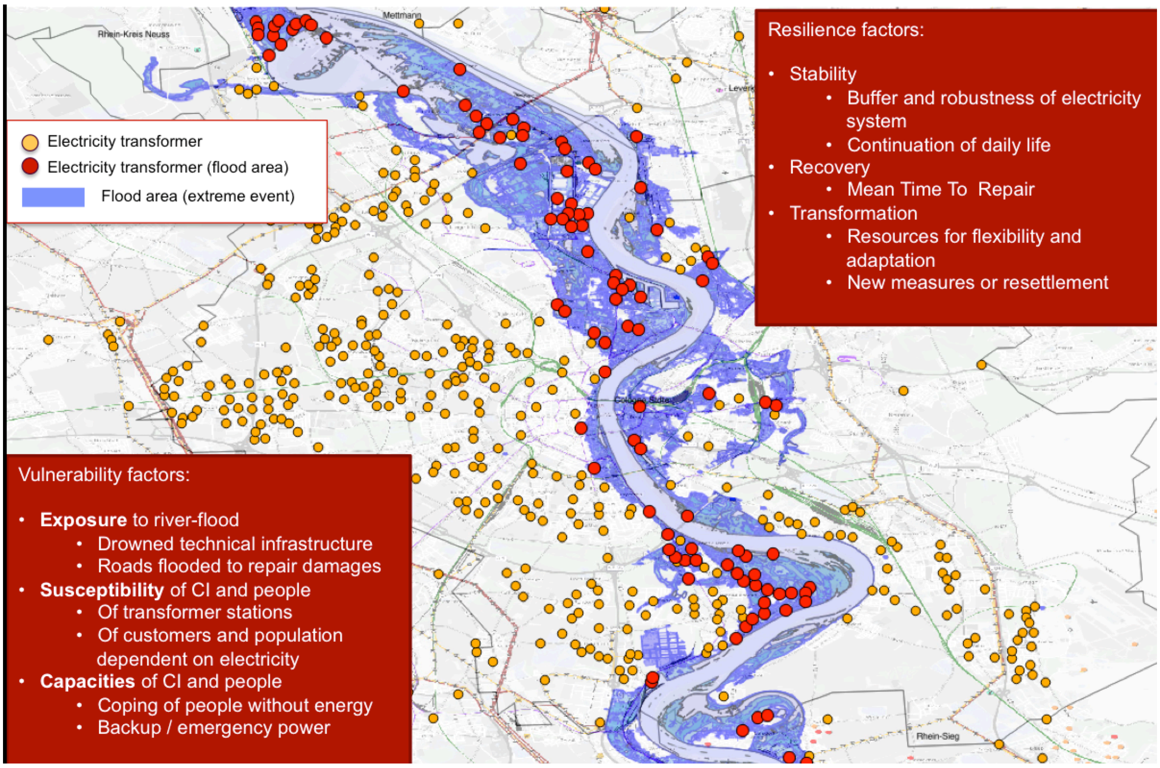


Figure 15 Vulnerability and resilience factors separated into differing factors that can be analysed with spatial information. The map shows examples of transformer sub-stations and an extreme flood scenario (HQ500 including failure of flood defense). (This figure, in similar layout, is also in (Fekete and Hufschmidt 2016) (P18)

One major discussion evolved around resilience in disaster risk contexts to broaden the perspective from a mere 'bouncing back' to also include a transformative, adaptive or 'bouncing forward' nature (Manyena, et al. 2011). The following Figure 16 tries to 'operationalise' this amendment conceptually, as it relates several existing terms and characteristics to either the bouncing back understanding of resilience (under the term 'restoration') such as experiences and capacities of people or organisations that enable people or systems to restore functionality after an impact. The other stream of resilience is displayed in Figure 16 under the term 'transformation' and contains alternative states or growth and development that people or systems might undergo when experiencing an impact or crisis. This is just a conceptual structuring that already shows difficulties in separation and overlaps with other existing 'umbrella terms' for some of these components such as vulnerability or complex adaptive systems. Yet using such structuring diagrams could help designating and documenting which resilience understanding and which components are investigated.

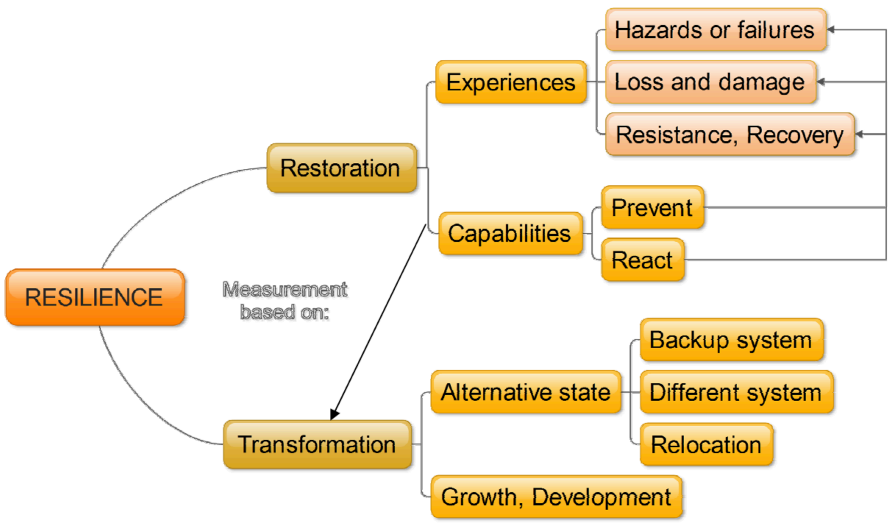


Figure 16 Conceptual overview on indicators important to capture resilience, for example, for urban areas (Source: author)

Narrow conception of resilience useful for operationalisation

The previous sub-chapter has illustrated how resilience in all its different facets could be a) separated from vulnerability (Figure 13) and then b) further structured according to two major internal characteristics – bounce back and bounce forward (Figure 16). While it is already possible working with this conceptual operationalisation of resilience by breaking it down into specific conceptual components, there exists an option for an even narrower understanding.

It differentiates two types of resilience:

A) resilience as a paradigm
B) Resilience as a measurable reduced component

While the usage of resilience in variant A) is common and followed by most researchers, it represents an on-going challenge for operationalisation. Correctly, there is important critique against any reduced understanding of a phenomenon measured quantitatively by a model or, risk indicator (See Fekete 2012b) **(P14)**. However, our own finding is also that this should not mean to abandon quantitative risk index research per se. The same scrutiny and rigor must be applied to qualitative approaches and methods as well. Variant A uses resilience as a resiliency, an overall desired state of a community or system. While this is a generally desirable condition and helpful strategic goal, it remains problematic for initial attempts at putting resilience in practice for the sheer complexity and inflation of aspects constantly attached to it.

Using resilience in variant B would allow for a stricter separation and enable operationalisation much easier. The following table (Table 8) shows an example for placing resilience into the dimension of several abilities that humans or systems they created might possess in dealing with disasters. One of such abilities is achieving a state of resilience. The exact placement of resilience as a sub-category of abilities would first of all point to the meaning of the word translated from the Latin origin of jumping back. Jumping back only occurs after jumping somewhere – in context to disasters as a reaction after as stressor enacted upon an exposed element. The ability to jump back can stem from internal abilities or is aided by external abilities. The general ability of jumping demands for the skill and knowledge of doing it but also for the capacities and resources for doing it.

Of course, resilience can take place in several time phases and in different speeds. However, for 'bouncing forward' already the term adaptive capacity is well established. And transformation is more than resilience – it is driven not only by the resilience process but also by pre-existing conditions.

In the coping phase, the system or human does not return to normal or another condition already, except for the condition to withstand and bear the moment of impact. Resilience would be the following phase of a change of condition into a process to get back to another, more preferable condition.

And before a stressor impacts the system preparedness for resilience can be carried out, such as gathering the resources and training the skills necessary to be able to 'jump back' when the stressor finally hits. But resilience as a process or action can sensu structur only take place after the hit.

Table 8 Placement of resilience within the specific time phase of recovery

Risk is a function of:	**Values**	**Benefits, Chances / Hazards, stressors and threats**	**Vulnerability**	**Dynamics**
Dimensions (examples)	• Human rights • Strategic values (risk mngmt goals)	• Man-made • Technological • Natural	• Exposure • Susceptibility / Sensitivity • Abilities	• Stability phases • Changes

Sub-categories (examples)	(risk mngmt goals:)
	• Live and health
	• Peace and order
	• Economic prosperity
	• Environmental conservation
		• Prosperity /gains Sabotage
		• Terror
		• Accidents
		• Epidemics
		• Cyclones
		• Earthquakes
		• Floods
		• Climate
			Abilities:
			• Prevention
			• Preparedness
			• Coping
			• **Recovery**
			    • **Resilience**
			    • Restoration
			    • Rehabilitatio
			
			• Adaptation	

	• Compliance • Etc.	extremes		
Variables (examples)	- Mortality - Econ. loss - Building damage	- Flood area - Flood depth	Resilience of CI: Rapidity of bounce-back: Ability of hospital to restore functionality after blackout (internal and external)	

Table 8 is a conceptual attempt at classifying risk as a function of several items under consideration in an assessment: values, hazards and threats, stressors, but also taking into account benefits and chances offered by taking risks, vulnerability and dynamics. Within those items, dimensions exist that can be further classified into sub-categories and variables. The main purpose is to demonstrate how and where resilience could be put in order to enable a stricter differentiation to pre-existing other terms. Resilience, in this classification, is a sub-category of the abilities dimension of vulnerability.

This classification does not rule out other facets to be ascribed to resilience; for example, resilience could also be argued to be nested within coping or adaptation sub-categories. However, in order to provide a consistent and limited description of resilience fit for operationalisation, we limit it to the designation in the classification only under the time phase after the stressor force ceases and the system under pressure starts to shift its status – upward back to a better condition. The following table (Table 9) further details this classification and shows how resilience as a specifically labelled ability itself is composed of or has resemblances to similar terms such as elasticity or flexibility as more specific characteristics, skills or techniques to achieve resilience. Table 9 also shows that any 'ability' is just a generic description that itself needs to be structured according to DRM phases, specific skills and finally, needs capacities and resources to enable performance of such abilities. Capacities and resources can further be described to consist of three generic sub-types (compare with the generic criticality types in Fekete 2011 **P13**); amount of resources available, time phase in which they are available and quality aspects such as whether the resources are provided internally or externally. Table 9 is, just as Table 8 just a conceptual and exemplary classification, therefore, certain boxes such as for adaptation are not filled with content, since the focus here is mainly on resilience understood as the variant B, a very reduced form for operationalisation.

Table 9 Further differentiation of 'Abilities' at the example of resilience

Ability types according to:	**DRM phase**	**Labelling of specific ability type** (examples)	**Specific skills or techniques** (examples)	**Capacities / resources** Qualifiers: • Amount • Rapidity • Internal/ external
	Prevention		Planning Storage	
	Preparedness		Defense Training Warning	
	Coping		Absorption Buffer Protection Reserve / Redundancy Resistance Self-help/protection	
	Recovery	**Resilience** Restoration Rehabilitation	Aid Elasticity Flexibility Rescue …	Example: number of external rescue personnel available within 8 minutes
	Adaptation			

In Table 9, resilience is a sub-component of the recovery phase. Resilience is the 'bouncing back' process and this process is dependent on the system characteristics such as internal characteristics, for example, elasticity or flexibility, but also on external characteristics such as aid or rescue. All of theses specific skills or techniques are however, based upon certain aspects such as knowledge, training and planning. As knowledge is important for every planning step in a disaster path or cycle or evolution model, it is not mentioned in each and every cell in table 9 explicitly. Knowledge on how to conduct rescue, for example, has to be gained in advance or instantly, in order to be able to use this skill. This example may help to bridge the gap between this reduced understanding of resilience and the currently more common broader understanding of resilience to encompass all phases of the disaster cycle, especially, the ex-ante phase. Resilience is an ability, conceptualised, trained and planned in advance, but will take in once specific time phase, after the impact, when the hazard stress releases the system to bounce back.

Certainly, analysing only the bounce back aspect of a technical system in a quantitative way will rightly provoke criticism for not capturing the human dimension, the bouncing forward dimension, the complexity and contexts and so forth. But it is a standard scientific method to conduct analyses, which by definition narrow down a subject to measurable components. Resilience as variant B is meant in this sense and for this specific purpose. It doe not say that it must not be accompanied by multiple additional components and models and methods to capture the overall resiliency of variant A or, of the risk to a city.

4.10 A concept for a place-based assessment in urban areas or regions concerning their critical values, infrastructure services and most vital elements

The final goal of KritisKAT project (at BBK, 2009-2012) was to develop a national priority cadastre of National CI (NCI). The results however, cannot be disclosed here of this cadastre, since it contains sensitive information that might be misused by saboteurs and attackers. It was one of the major constraints during this project that even publicly available information could not be aggregated and stored centrally, since this could create a security risk. The outcome of KritisKAT for the public is mainly a methodology how to identify CI. Some of the results of the project KritisKAT are currently in preparation for a publication at the Federal Office. Table 10 shows however, an example of how national priority lists may look like.

Table 10 Example of a Critical infrastructure national priority list (Fekete 2011: 21) (P13)

	Top 10 suppliers (for example by market share)				**National icons / rare yet important key services or elements**			
Infrastructure capability								
Sector A	1	2	3	…	1	2	3	…
Sector B								
…								
Civil protection impact dimensions								
Critical proportion / impact extent Number of people supplied (by A1, A2, … B1, etc.)	Sub-national		National		Sub-national		National	
	International		Global		International		Global	
Critical time Impact realization = speed of onset to impact human life or health	X minutes, hours, days …				X minutes, hours, days …			

The methodology was further developed in order to be conducted in case study regions. In order to derive a methodology feasible to be conducted with minimal resources, the approach to be taken would have to be simple. The following figure shows the steps to be undertaken in order to identify CI at city or community level.

The first step (Figure 17) is the identification of the whole assessment's purpose, by identifying the overall goal. This goal is called risk management goal (Fekete, et al. 2012; Fekete 2012a) **(P5, P6)**, but in German literature it is more established under the term protection goal (German: Schutzziel, see (GFOCD 2010b; FMIG - Federal Ministry of the Interior of Germany 2011). The reason not to name it protection goal is grounded on the limitation of the concept of protection as a predominantly top-down expression of service provided by a superior agency, which renders other stakeholders such as the people, local governments or CI operators as passive information and order recipients. This does not mean that protection level approaches are necessarily so, they include as much modern conceptual notion as many Anglo-Americans terms such as community resilience or risk register target levels. However, much conceptual work is shifting and balancing between paradigms of past and future, specifically around the term ´resilience (Fekete & Hufschmidt 2014) **(P17)**.

Figure 17 First step in CI identification – value affected by possible failure (in: Fekete Lauwe Geier 2012) (P6)

The choice of either life or health to be put first or economic survival is often not explicitly documented by companies or civil protection agencies, but is a necessary step to structure the actions in the consecutive steps of analysis. Research on values and basic needs is still wanting in modern connotations in how far they should be incorporated into basic security and resilience concepts and methods. While Maslow's basic need pyramid is often used simply since there is no known alternative to many practitioners, the field of CI can also be advanced by investigating similar concepts such as ecosystem services (MEA 2003), or the commons (Dietz et al. 2003), but also root cause concepts of vulnerability (Blaikie et al. 1994).
The next step (Figure 18) identifies critical time, after which an impairment or failure of CI would result on affected people or other parts of the CI system. Critical time is one of the three generic criticality criteria (Fekete 2011) following the identification of critical quality in step one. Timing has been used in a range of criticality assessments, including projects carried out or supervised by the author of this volume. KritisKapa has been a project carried out expert interviews among different CI operators and compared different lengths of impacts and recovery capacities (hence: Kapa in the short name for German Kapazitäten). The results were classified as sensitive information by the Ministry of the Interior and can unfortunately not be documented in this work or any public source. But other projects (GFOCD 2014) have also successfully worked with time-aspects of CI. Critical time hence is one decisive factor that can also be used for a wide range of CI, despite the great difference in system and service type (Figures 18 and 19). In one of the case studies critical time was analysed in terms of recovery speed and in another critical time in terms of accessibility of flooded hospitals (see later chapters).

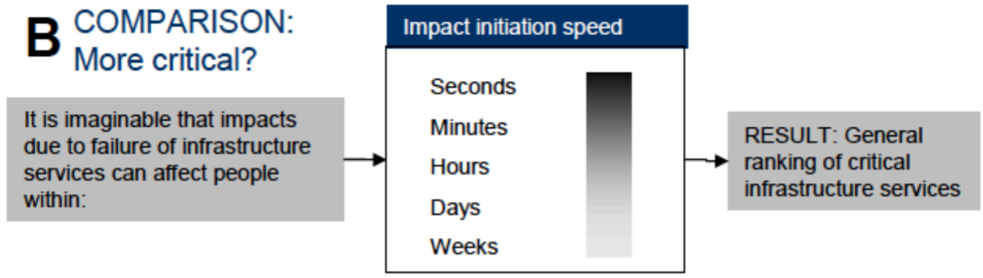
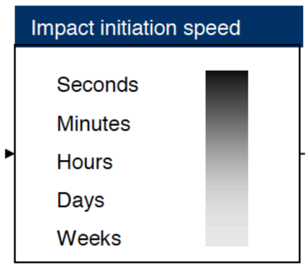


Figure 18 Second step of CI identification – ranking of CI using time factors (Fekete et al. 2012: 346) (P6)

Comparison of services within one sector (example)

Sector	Service	Value: Life & Health	Time-critical within	...
Water supply	Cooling water	Yes	Minutes	...
Water supply	Water for fire fighting	Yes	Seconds	...



Comparison of sectors (example)

Sector	Service	Value: Life & Health	Time-critical within	Value: Wealth & Economy	Time-critical within	...
Water supply	Water for fire fighting	Yes	Seconds	Unknown		...
Finance	Stock exchange	Nein		Yes	Seconds	...
Information Technology	Information (Warning)	Yes	Seconds	Yes	Seconds	...

Figure 19 Example for resulting ranking according to time until failure will impact a CI service (Fekete et al. 2012) (P6)

The third and last step (Figure 20) finally sets the geographic context and identifies CI in a region or location. This represents the third generic criticality criterion, time. While this is a standard approach in any geographic study, within CI there are few studies explicitly focusing on perimeters, topography, spatial networks or any object outside the technical system. However, for local communities, this is the decisive view on how they can be affected by CI failures, be it from services internal or external to their community. The identification scheme is very simplified here by asking after biggest suppliers, monopolists and network dependencies. However, especially the latter question is often more complex than assumed and many expert interviews with CI operators, local governments or emergency managers revealed a lack of any information about supply chain dependencies. Since this last step is important, another scheme has been suggested to navigate analyses to be carried out in a simple manner by researchers as well as practitioners with a research interest alike.

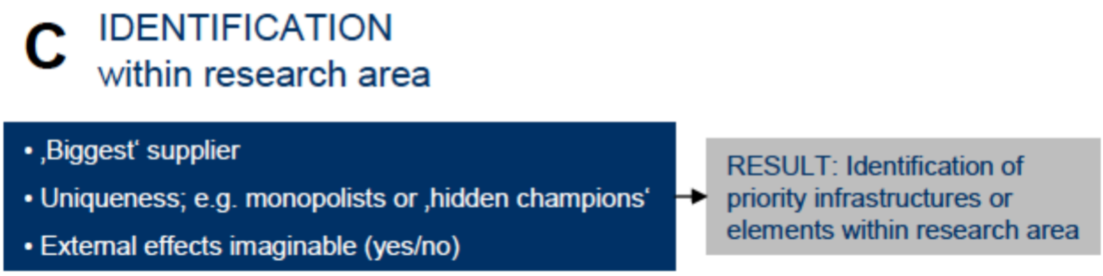


Figure 20 Third step in CI identification – criteria for identification within a specific regional context, e.g. a city (Fekete et al. 2012: 347) (P6)

Figure 21 shows five steps to identify CI within a region and the design follows the design existing for investigating the vulnerability of communities regarding the criticality of an infrastructure. While the vulnerability scheme (GFOCD 2010a) intents to identify the priority to further investigate the vulnerability of one specific CI element within the capacities provided by the CI operator, this scheme suggested here is more suited to identify the importance of the CI services provided from the perspective of the local population. However, it does not guide how to conduct a social vulnerability assessment, differentiating "the population" of a region yet. This scheme only bridges the vulnerability of a CI with the vulnerability for a region. In later steps this will be advanced with social vulnerability assessments of people, as indicated in one case study, in which also experience on opportunities and limitations was gathered (Fekete 2012) **(P14)**.

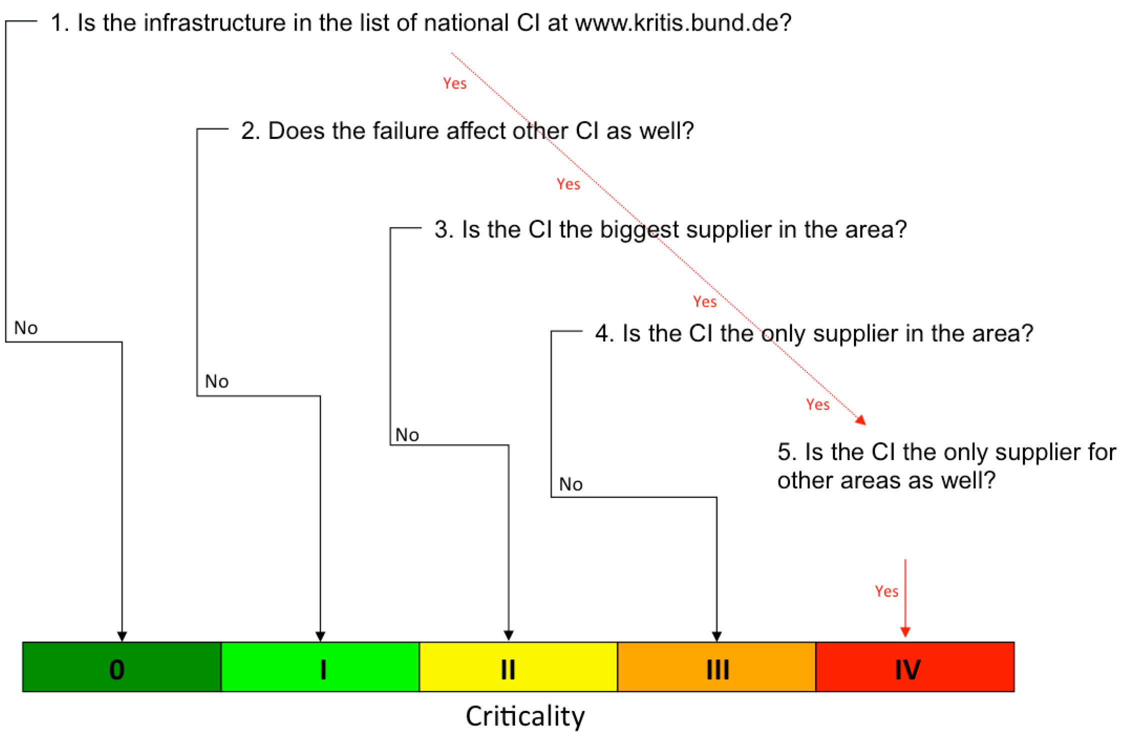


Figure 21 Degrees of criticality derived after a simplified decision method for sub-national level (Source: author)

The whole purpose of this volume is to suggest a conceptual model on how to conduct a CI assessment within a concrete geographic context. While at the one hand the following case studies will highlight some approaches how this can be carried out, they will not be sufficient to cover in depth all aspects to be debated. Briefly, it was investigated how other researchers have meanwhile utilised or critically reviewed our suggested concepts:
The common criteria for assessment of Critical Infrastructure (Fekete 2011) **(P13)** have been cited by 30 other papers (plus three from our own group). Five of them in Chinese, Czech or Russian language could not be assessed. From the remaining articles one designates CI in European countries (Novotny et al. 2016) by referring to the division of functional specifications of CI, being more than just technical asset in our article, the common criteria, criticality evaluation.
Another article on flood management (de Bruijn et al. 2016) refers to the importance of secondary effects, cascading effects and interdependencies in our article.

Main findings of chapter 4 'Conceptual Model and Methods Used in This Study'

Chapter 4 mainly contributes to the research question:

Techniques and applications

3. Which techniques such as methods of risk and resilience assessment can help to better understand urban disaster resilience?

   ->Q3. Many risk assessments are lacking awareness and concepts to embed the steps of analysis into a bigger project management framework **(P6)**. In addition, an understanding about the goals of such risk assessments is often missing, not clearly articulated or hidden for reasons such as different interests of stakeholders. The paper **P6** presents a methodology how to identify strategic goals and a guided stepwise structured process in identifying societal values at risk and combines it with criticality criteria. The outcome is a procedure to identify critical infrastructure of national priority also at community level.

   Existing assessments of critical infrastructures were often only focusing on technical elements and lacking a general basis for structuring those elements. The paper **P13** extends the notion of critical infrastructure to include humans and the environmental conditions. Generic criticality criteria were established to allow unilateral identification, comparison and ranking of critical infrastructure elements and processes across all sectors. A national priority list and ranking of CI procedure is outlined.

Main findings of the chapter in overview

The main outcome is a stepwise methodology to assess critical infrastructure in context to urban resilience. This stepwise process has been described in detail in this chapter and will be briefly summarised in the figure and tables below.

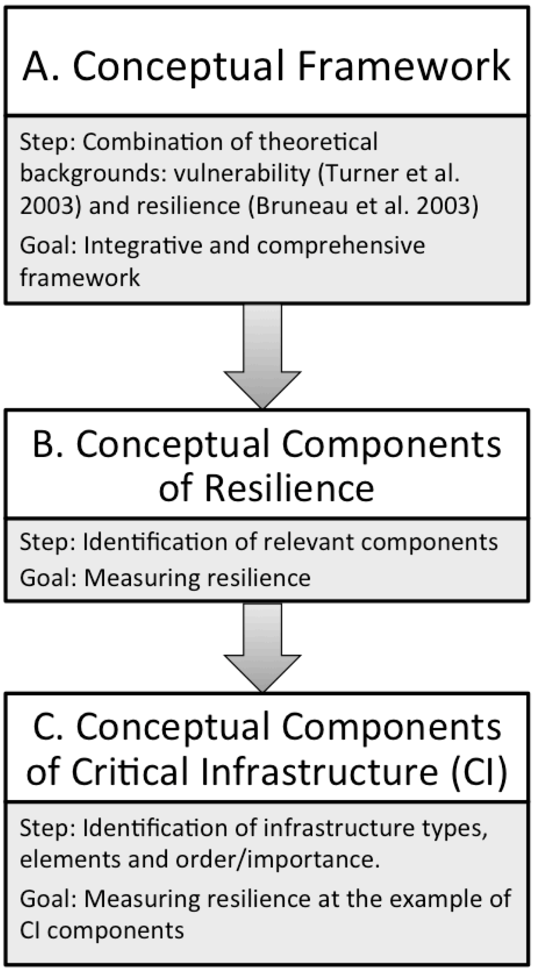


Figure 22 Three basic steps of the model to analyse critical infrastructure as parts of resilience of a place of investigation (for example, a big city) embedded into a risk management process

While Figure 22 has summarised the sub-chapter of chapter 4 into three basic blocks, the following tables offer an overview on how each individual conceptual part of the models presented in the 10 sub-chapters is to be placed into a stepwise order when assessing critical infrastructure as parts of resilience of a place of investigation (for example, a big city) embedded into a risk management process.

Table 11 Step A. Framing the concept and overall approach of resilience embedded in risk management

Step	Objective	Method established	Ref
1	Identifying the time phase of analysis	Risk and crisis management disaster time phase cycle applied to German civil protection context and language	**Figure 8 P23**
2	Placing assessment into a comprehensive management process	Risk management project process cycle in modified version	**Figure 9 P6**
3	Identifying the role of Critical Infrastructure within a hazard-impact model	Model of multiple man-made and natural hazards that affect Critical infrastructure which in turn affects multiple dimensions of human values	**Figure 10 P6**
4	Detailing interdependency types	Model for identifying impact chain and type of impact – primary, secondary or in combination	**Figure 11**
5	Identifying the role of resilience within risk assessment	Resilience process model which distinguishes resilience from risk and vulnerability in order to enable operationalisation	**Figure 13**

Table 12 Step B. Identifying conceptual components of vulnerability and resilience

Step	Objective	Method established	Ref
6	Differentiating vulnerability and resilience	Vulnerability and resilience factors separated into differing factors that can be analysed with spatial information.	**Figure 15 P18**
7	Differentiating and structuring resilience components	Conceptual overview on indicators important to capture resilience, for example, for urban areas	**Figure 16**
8	Narrowing down resilience components	Placement of resilience within the specific time phase of recovery	**Table 8**

Table 13Step C. Identifying conceptual components of critical infrastructure

Step	Objective	Method established	Ref
9	Identifying general infrastructure components	Infrastructure components classification advancing existing CI models on integrating human staff and environmental components	**Table 6 P13**
10	Identifying CI components within spatial contexts	Generic criteria classification for Critical Infrastructure identification that captures spatial, but also temporal and quality aspects	**Table 7 P13**
11	Detailing impact and focus of interdependencies	Concept for merging technical systems and humans in criticality assessment of infrastructures (Three indirect impact layers of infrastructure failure) – integrating and detailing previous steps 3, 4 and 6	**Figure 14**
12	Generic ranking of CI	Example of national priority list	**Table 10 P13**
13	From generic to place-based identification and ranking of CI	Stepwise guideline to identify a) values b) urgency to act and c) assets of CI in a specific area. Integration and applying previous steps 6,7 and 9	**Figures 17-21 P6**

5. Case Study – Ex-ante risk and resilience assessment of an urban area using GIS: Cologne area

This case study will apply the conceptual and methodological outline provided in the previous chapter in a case study. By focusing on an ex-ante perspective of resilience, an assessment is carried out using spatial data combined with statistics and expert evaluation. The case study aims at an assessment of potential future risks and how they interrelate with urban resilience and critical infrastructure. This chapter adopts recent research and summarises published papers on different facets of resilience and how they are assessed. The main purpose in this chapter is to demonstrate how such assessments can be conducted, responding to a prevalent demand in the community on how to put resilience into practice.

One of the main questions is how to operationalize resilience, i.e. how to put the rather theoretical concepts of resilience into practise, how to 'measure' or assess resilience, be it quantitatively or qualitatively. In this chapter, the main focus is on semi-quantitative approaches and utilise publicly available information in order to derive novel empirical results out of novel data aggregations.

Out of the wide range of possible indicators of resilience (Figure 16), only a few individual indicators are selected and explored in depth. While research was previously conducted on risk mapping and aggregated vulnerability indicators at national level (Fekete 2010; Fekete 2009; Fekete et al. 2010), the focus now is on sub-national level, on resilience instead of vulnerability, and on individual indicators rather than on composite indices. In the course of preparing the research for this volume, it was possible to summarise our experience and reflections on past attempts on indicator developments, their shortcomings and challenges (Fekete 2012b) **(P14)**.

5.1 The Conception and Methodology

The conception to conduct a resilience assessment builds up upon existing resilience frameworks having their roots in ecological systems research (Turner et al. 2003) that have also been applied in contexts of place-based risk, vulnerability and more recently, resilience assessments (Cutter et al. 2008) and combining it with approaches that bridge between technical and societal aspects of critical infrastructure and resilience (Bruneau et al. 2003). The individual resilience indicators stem from baseline definitions of resilience (UNISDR 2009) and expert groups that have decided upon selected key indicators of resilience combining both technical and societal aspects (Bruneau, et al. 2003). However, explicit spatial research on resilience, has been missing. For example, recognition of scale and scale effects (Gibson et al. 2000; Fekete, et al. 2010), area unit and spatial autocorrelation (Cao and Lam 1997; Openshaw 1984). Within Critical Infrastructure policy (US Government 1996; European Commission 2008) and related research (US NRC – National Research Council 2012), a mainly technical perspective had been prevalent with a focus on physical elements. However, it was proposed to advance this conception by integration of the human staff, non-structural assets and the environment (Fekete 2011). While national strategies on CIP were being put forward to stimulate concrete actions (FMIG - Federal Ministry of the

Interior of Germany 2009), a large body of research on CIP pursued certain goals such as saving lives or restoring national control in a rather implicit manner so far. Therefore, the need to provide a comprehensive methodology has been identified that includes goals of management, so-called protection goals or risk management goals (Fekete 2012b, Fekete et al. 2012). It has also been found relevant to link this methodology to generic indicators (Fekete 2011) for assessing CI importance first, what often is termed 'criticality' (FMIG 2009). Such goal-driven strategic plans and thresholds can be found in many fields of security and risk research (Fekete 2012c) **(P5)**, but only lately multi-disciplinary resilience research is becoming aware of it and translates such rather theoretical conceptions into applied assessments (Fekete, et al. 2016; Fekete et al. 2017) **(P1, P10)**.

Methodology

The case study utilises the conceptual steps developed and shown in the previous chapter. The three basic steps of conceptualisation (Figure 22) are used and followed by the steps of assessment of Critical Infrastructure in the case study area, in Cologne, Germany (Figure 23).

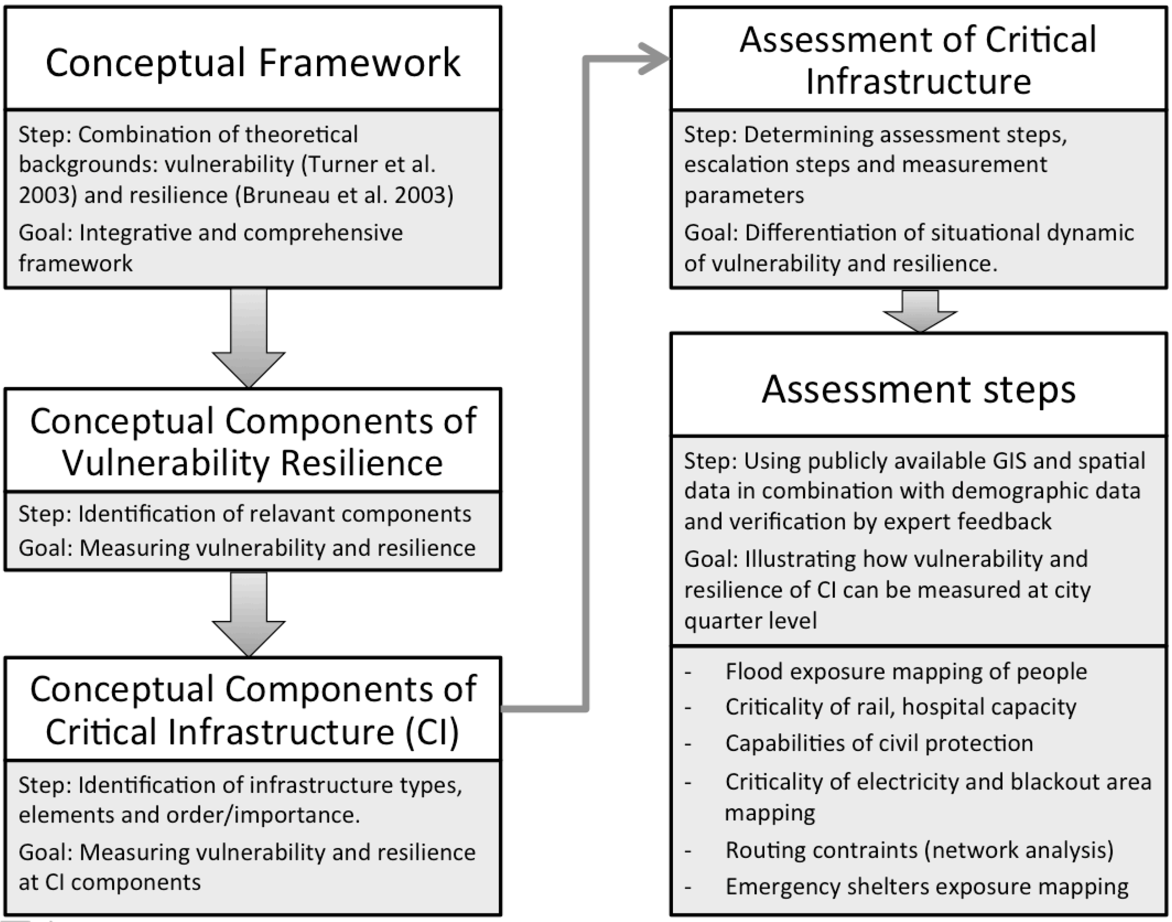


Figure 23 Conceptual and methodological steps applied in the case study (Fekete et al. 2017) (P10)

Publicly available open street map data and open government-type of documents from the city of Cologne have been the main data basis for conducting a GIS-based assessment of population and power supply at risk during an extreme flood scenario in the city of Cologne (Table 14 below).

Table 14 Assessment steps carried out in the assessment (Source: Fekete et al. 2017, P10**)**

Order of analysis steps	**Escalation steps**	**Possible measurement parameters**
1. People at risk: residents and visitors	Buildings and locations exposed to the flood	Exposure: number of residents and visitors Vulnerability: composition of population
2. Everyday infrastructure dependencies (electricity, water, food, hospitals, daily emergency management)	Basic services such as water and energy not functioning, roads blocked	Number of elements per infrastructure exposed Most critical elements amongst them: largest supply volume, specialised services
3. Back-up infrastructure at risk itself: fire brigades, hospitals, THW	Emergency services such as fire brigades are on max. capacity – cannot serve all	Number of elements per infrastructure exposed Most critical elements amongst them: largest supply volume, specialised services Vulnerability as dependency on secondary infrastructure (below)
4. Secondary infrastructure that the back-up infrastructure is dependent upon itself	Emergency services themselves are slowed down or in degraded service	Selected examples: roads and electricity
5. Shelters in operation – and at risk	Shelters at full capacity,	Shelters at risk itself, also additional situation of refugee crisis

The following section is a direct quote from: "Spatial exposure aspects contributing to vulnerability and resilience assessments of urban critical infrastructure in a flood and blackout scenario", published in Natural Hazards: (Fekete, et al. 2017) ***(P10)***

„Data sources used for the hazard zonation include an extreme flood scenario that includes an over 200-year flood return period river discharge with additional exceedance on top and including the assumption of dyke breaches and failure of flood defence in general. These data are obtained from the Rhine Atlas from 2001 (IKSR 2001) and its new online version with updates from 2015 (ICPR—International Commission for the Protection of the Rhine 2015). We use additional data, kindly provided by the city of Cologne, based on their own flood zonation maps, derived from LIDAR data, and openly available. The Cologne scenario is termed as HQ500, hence, a 500-year return period. All return period models undergo changes when additional flood events, such as in 1993 and 1995 and later, modify knowledge and calculations of the return periods. Certain assumptions of extreme flood extent calculations possibly have to be considered false. The estimated flood zone is the calculated maximum zone at any section of the river. In reality, a flood is dynamic and maximum flood wave heights differ largely between the river sections.

Accessing critical infrastructure data is difficult because of data sensitivity issues. This also influences the assessments carried out in this paper, since data privacy or security concerns because of possible saboteurs or terrorists have to be considered. Therefore, exclusively open-access data were used. OpenStreetMap data were used from certain providers such as geofabrik.de and FLOSM.de, but also open data archives from the city of Cologne (offenedaten-koeln.de) and from GIS companies (opendata.arcgis.com). Accuracy and data completeness were checked with other available data such as online maps and reports from the statistical offices of the city. Data for hospitals and their capacities were taken from annual quality reports available online. However, one constraint here is the inconsistency of data sets, since some reports were available for 2015, but many more for 2014 and older. However, we assume this is not a major problem, since hospital capacities largely remain in similar boundaries within just one year of difference. Still, this is a constraint of data availability and room for improvement for future follow-up studies. Shelter data are one of the most sensitive issues, since misuse by attackers from nationalist groups must be considered. In fact, some of the first to publish information about refugee shelters during the current in-migration from civil conflict states, such as Syria, Afghanistan, Iraq and others, were right-wing nationalists. Therefore, the addresses are not disclosed here and the maps generalised in scale. Additional data from Web Mapping Services (WMS) had been used during the process, but not in the maps provided in this paper. The geoinformation system (GIS) used is QGIS, while some analysis also ran on ESRI products.“

5.2 Results of the Assessment

The following section is largely based upon the paper: "Spatial exposure aspects contributing to vulnerability and resilience assessments of urban critical infrastructure in a flood and blackout scenario", published in Natural Hazards: (Fekete, et al. 2017) ***(P10)***

The results of the assessment (Figure 24) show that even fire brigade stations, which should have the best knowledge about risks such as floods, are situated within the flooded zone during an extreme event, as are certain hospitals.

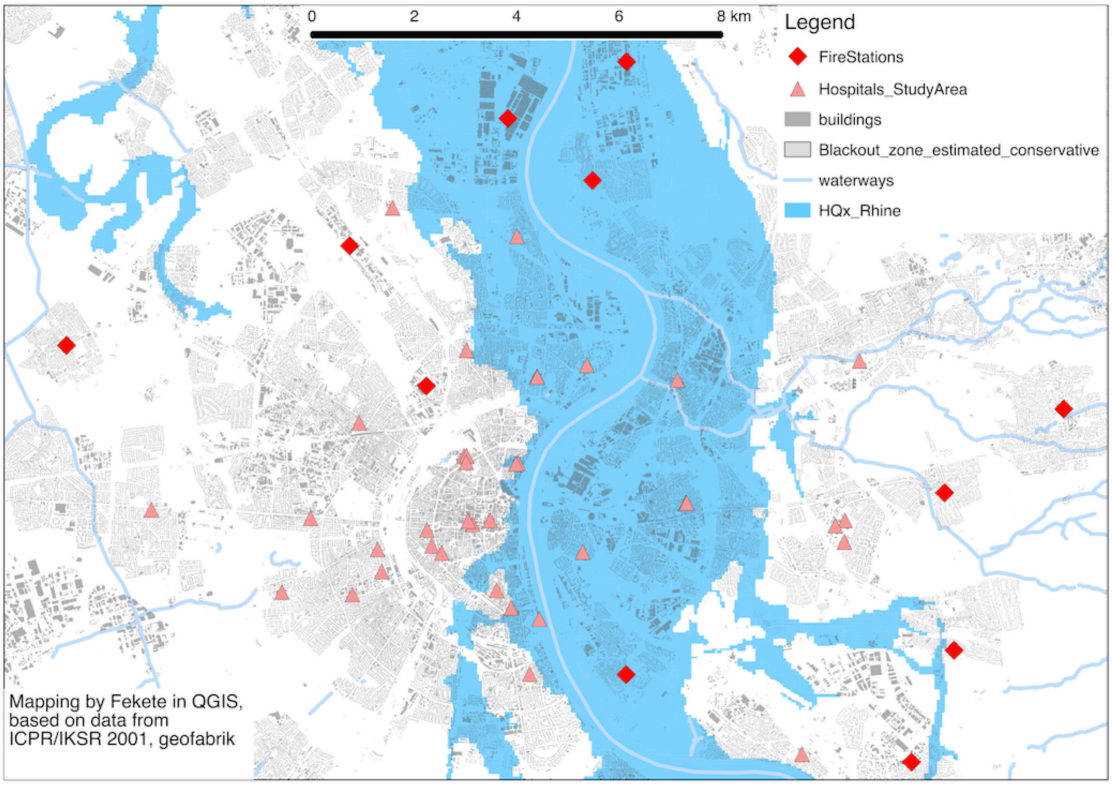


Figure 24 Exposure of hospitals and fire stations to an extreme flood scenario (named HQx; HQ500 including failure of flood defense and groundwater intrusion) (Source: Fekete et al. 2017) (P10)

The area of hypothesised exposure to floods (blue area in Figure 24) can also be applied on elements of electricity system. The research question here is, which of the electricity supply will fail due to the flooded elements? This is not easy to answer as our research showed. A hypothetical map has been created with a more cautious and a less cautious estimated blackout area (Figure 25). In the more cautious approach, the area of likely blackout has been mapped using a GIS and connecting those transformer sub-stations lying fully within the potential flood scenario area (HQx). In the less cautious approach, also the area between the last flooded transformer sub-station and the next one outside of the flooded area has been mapped. The reason for this is that it can be assumed that this area between flooded and next non-flood transformer sub-station might also be affected by a failure of the elements within the flooded area. When shown to the electricity grid operator the response was quite affirmative that the hypothesised blackout area is quite plausible. Future research may use more sophisticated methods such as voronoi polygons and modelling. However, this is very much dependent on data provision by the operator.

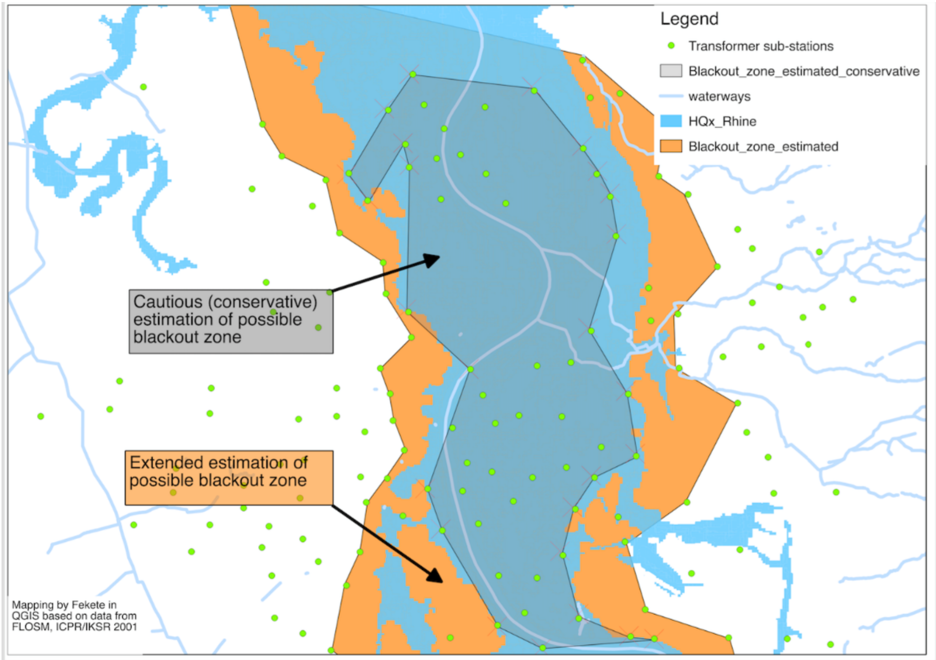


Figure 25 Estimation examples of possible impact area of blackout (Source: Fekete et al. 2017) (P10)

Until now, most spatial risk algorithms treat polygon boundaries as boundaries of estimation. However, this does not reflect the real situations on the ground in case of a real flood crisis. When hospitals lie in flooded zones, the fire brigade and rescue cars still need to access them. While they would naturally avoid flooded areas (polygons) they could still drive through roads that are flooded only up to some centimetres. The GIS tool used in ArcGIS allowed computing routing through flooded polygons (Figure 26), though by reduced speed (assumed delay factor used in network analyst). This is an improvement as compared to previous tools and approaches where barrier polygons are used and routing stops completely at the perimeter of the flood polygon. That would mean that even a street flooded by only 1 centimetre in height would not be crossed by cars anymore which is unlikely to represent reality. Still however, future research is necessary, for instance on improving the parameter of car driving speeds and maximum flood heights that cars and trucks can pass.

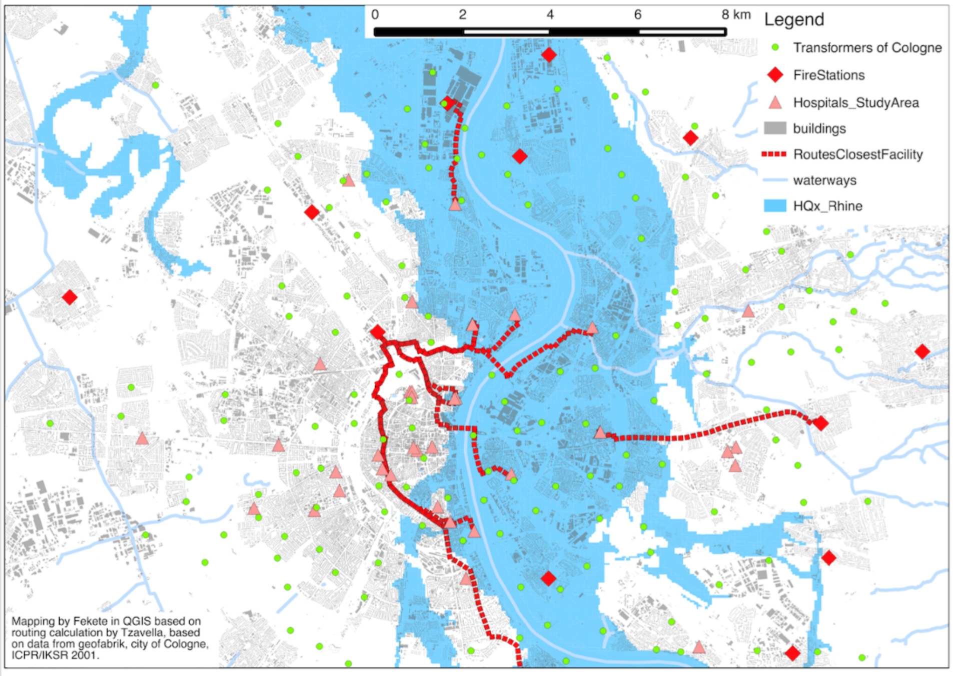


Figure 26 Visualization of shortest path routing from the closest fire stations (red diamonds) to the flooded hospitals (triangles) using as a time scaled cost barrier the flooded area (delay of emergency response due to reducing of speed increased driving time). (Source: Fekete et al. 2017) (P10)

These assessments were extended on other points of interest that might need to be served during crises situations such as floods. One example are shelters or refugee housings (Figure 27), which became a new and eminent topic after the refugee immigration in 2015.

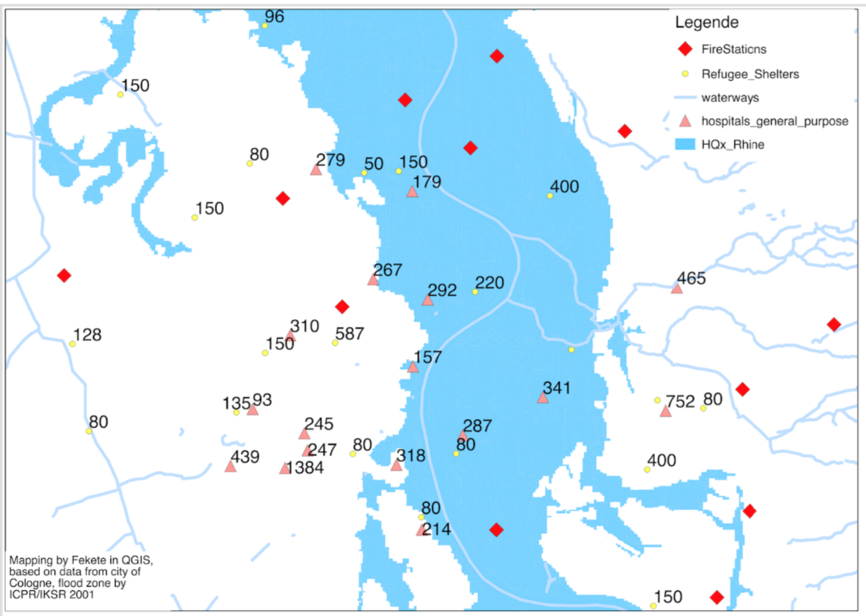


Figure 27 Map showing the locations of flood-exposed shelters (yellow dots) and hospitals (triangle) with respective numbers of beds per location. (Source: Fekete et al. 2017) (P10)

The following sections are largely based on the paper by Katerina Tzavella, Alexander Fekete, Frank Fiedrich (2017). Opportunities provided by Geographic Information Systems and

Volunteered Geographic Information for a timely Emergency Response during flood events in Cologne, Germany. *In Special Issue in* Natural Hazards*: "Recent innovations in hazard and risk analysis". (under review)* ***(P11)***

Resilience, as understood as a rapid recovery or restoration of functionality after disaster (see variant B in chapter 4 or Table 8) is further analysed in another article investigating the case study Cologne **(P11)**. The resilience of hospitals or refugee homes is dependent on emergency management such as ambulances and fire brigades that in turn are dependent on road (as a critical infrastructure) to enable accessibility. We have analysed differences in rapidity of access by road conditions varying between non-flooded and flooded situations. The maps in Figure 28 show the different routes in both cases. Using GIS functionality, the additional time needed to access hospitals during a severe flood event can be computed.

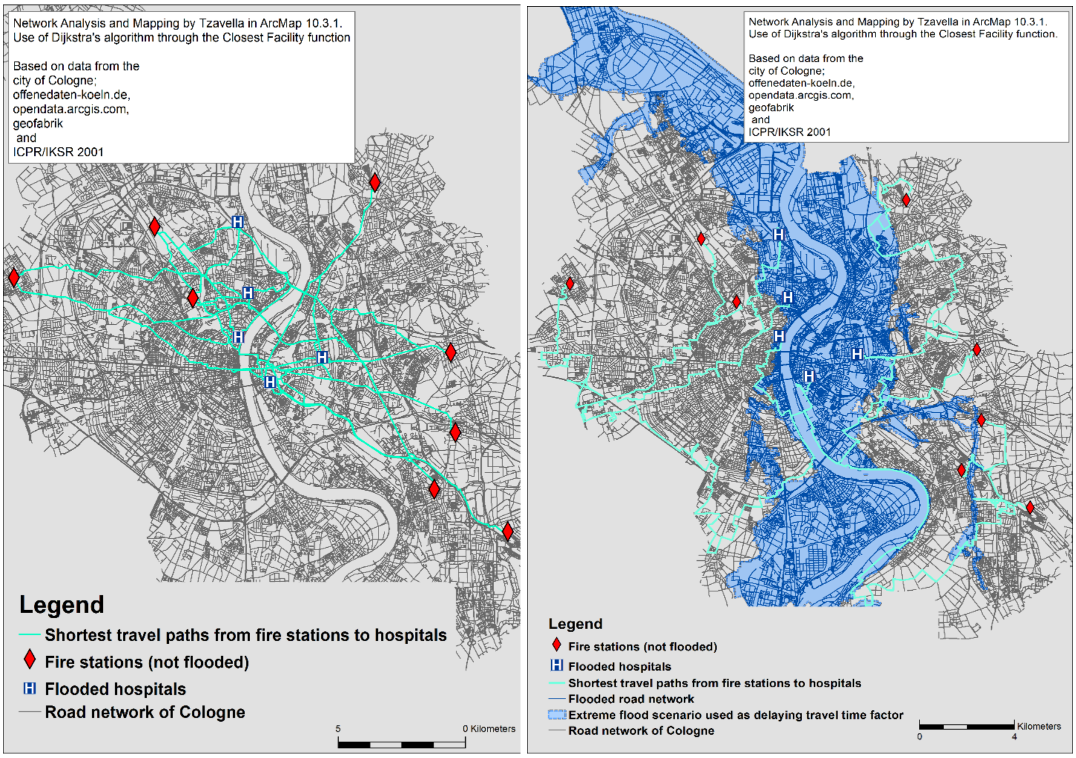


Figure 28 Quickest routing paths recommended for timely emergency response aiming at assisting the affected from the flood hospitals before (left) and during the extreme flood scenario (right). Source: Tzavella et al. (under review) (P11)

We have carried out the same assessment also for refugee homes that are provided by the city after the influx of migrants since 2015. Accessibility can also be expressed by analysing isochrones that are designating areas that can be serviced within certain amounts of minutes (intervals) (Figure 29).

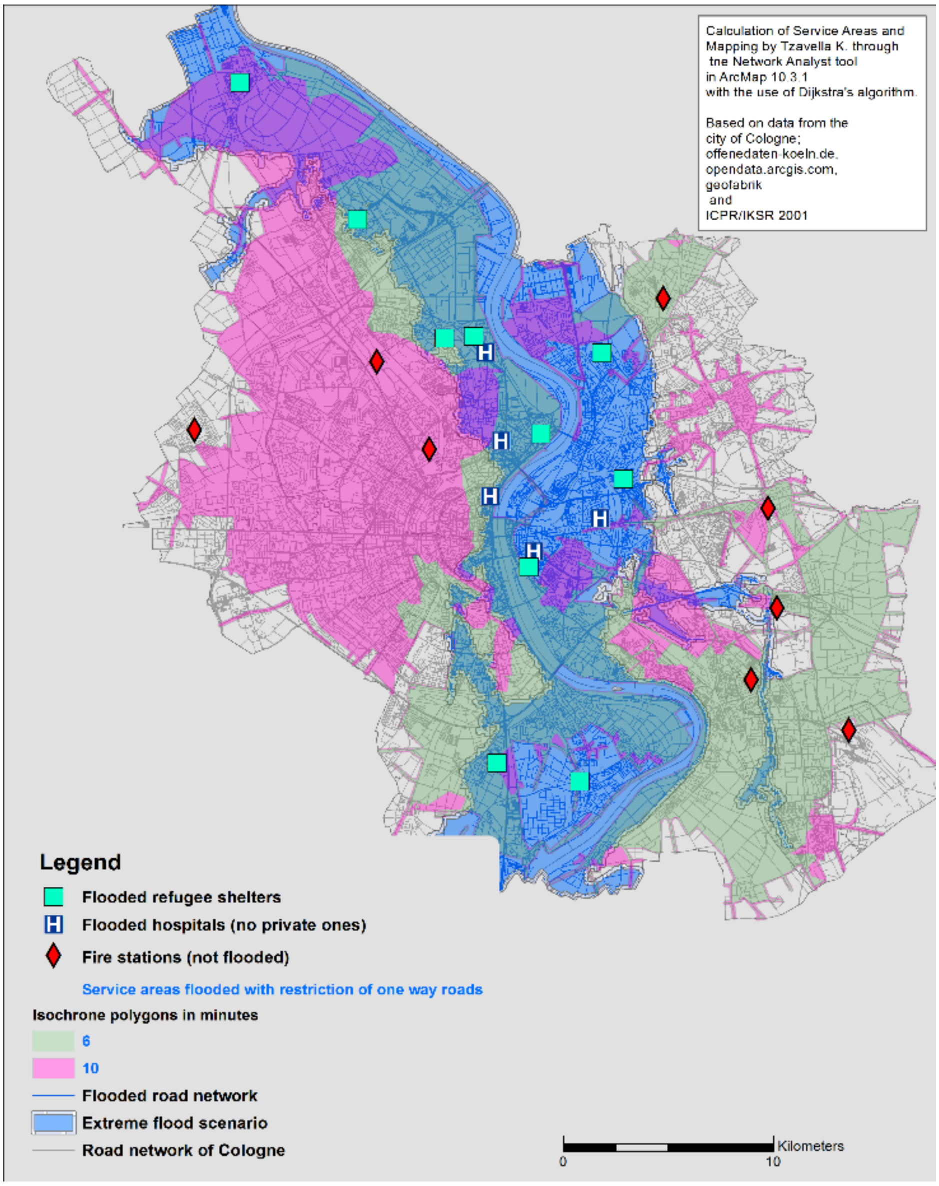


Figure 29 Isochrone polygons for 6 and 10 minute travel times during the extreme flood scenario with the restriction of the one way roads. Source: Tzavella et al. (under review) (P11)

5.3 Discussion of case study results

The results show that certain analyses that nowadays are standard features in a GIS; routing and isochrones analysis. The maps also show which points of interest of analysis lie within a hypothetical flood zone and might be damaged by a flood. The main purpose was here, however, to demonstrate that typical risk zonation assessments such as flood zonations, can be applied to and enriched by including Critical Infrastructure. There still exist few spatially explicit assessments of CI using GIS, and for the city of Cologne this is one of the first maps of its kind. It reveals that even fire stations would be flooded in a city very familiar with flood damage, and that also hospitals would be flooded. The connection however, between place-based risk assessment and CI is the main result here and the results indicate that also, resilience aspects can be operationalised in the sense of concrete spatially explicit assessments of locations of assets, distances and routing time needed to access them. The isochrones

maps have been shown to the expert responsible for computing such maps for the city of Cologne and he approved the results.
In the range of limitations, we may add to what is included in the paper (see below) that conceptually, of course this is a very narrow perspective on resilience; only one facet is analysed here; rapidity of recovery by road network accessibility. However, this accessibility also depends on number of alternative roads (redundancies) which are also taken into account by the isochrones mapping. Nevertheless, another critique might be valid; whether this depicts resilience or whether accessibility and isochrones maps have not already existed before being named resilience. This is of course true and it is just under a new focus that accessibility is regarded here as one of the many components that make up the ability of resilience for a hospital due to a hypothesised crisis situation where external help by fire brigades is necessary. This may be the case for a number of situations; fire fighting, emergency water supply or help with people stuck in elevators, coordinating evacuations etc.

The following section is a direct quote from the paper by Katerina Tzavella, Alexander Fekete, Frank Fiedrich (2017). Opportunities provided by Geographic Information Systems and Volunteered Geographic Information for a timely Emergency Response during flood events in Cologne, Germany. *In Special Issue in* Natural Hazards*: "Recent innovations in hazard and risk analysis". (under review)* ***(P11)***

"Shortcomings identified in our own work include assessments that carry only very rudimentary information about the vulnerability of infrastructure. For instance, in an index of aggregated social vulnerability for river-floods at county scale, we added another layer of infrastructure, but all information we could derive by using spatial information such as found in open accessible maps and aerial images were locations of certain objects such as refineries, power plants etc. Therefore, this information layer barely contained more information than the density of certain CI objects per county area.
Another challenge of matching CI asset assessments with affected population and their vulnerability is that traditional risk zoning is not enough. Risk zoning imposes a spatial area that is affected and in this case are the flooded transformer stations. However, as this paper has shown, this area is not necessarily the area of affected people. That area of residents and mobile population groups such as visitors, commuters, etc. might lie outside of the flooded area, since cascading effects of power failure cascade over larger regions that are difficult to estimate without the expertise of a CI operator company that possesses all monitoring information.
Underlying secondary infrastructure is energy, information, logistics, roads and other forms and services that enable other primary infrastructure such as hospitals, civil protection etc. And, electricity is also an underlying infrastructure enabling electricity production and distribution, too, for example.
While roads are important for human use in normal situations, in the case of a certain disaster scenario, roads can become vital when people need to be transported to hospitals, or organs and medical supplies need to be delivered etc. Roads are one of the most important infrastructures for providing access to hospitals and any other kind of shelter. Research on roads and transport adopted vulnerability and criticality assessments early on and apply them in network analyses also with geographic context (Jenelius et al. 2006). Furthermore, Jenelius in 2010, studied the vulnerability of the road network under area-covering disruptions (such as flooding, heavy snowfall or forest fires) and found that in contrast to single link failures, the impacts of this kind of events are largely determined by the population concentration, more precisely the travel demand within, in and out of the disrupted area itself, while the density of the road network is of small influence. Additionally, spatial risk assessments address road and route interruptions due to extreme weather events for example (Keller and Atzl 2014). Late examples of disasters such as Hurricane Sandy

2012 have shown the importance also of other transport routes such as subways flooded. Meanwhile, big amount of such collected spatial information can be updated and utilized in addition to the conventional authoritative data. People experiencing disasters may still be able to share messages and locations on social media websites, voluntarily supplying information regarding the affected areas via online social media, collaborative platforms or in-situ and mobile sensors, especially GPS-enabled devices (Middleton et al. 2014) leading to the gathering of the so called Crowdsourced or Volunteered Geographic Information (VGI) [1,10]. Such volunteered geographic information (VGI) has a varying quality; it can provide timely updates for estimating the disaster severity [12, 13]. Specifically in crisis situations, such as after the earthquake of Nepal in 2015, a timely information regarding the road network connectivity (i.e. whether a road segment is still accessible after a disaster or not), is very valuable for the decision makers since this type of information can be commonly observed and is critical for planning rescue routes (Hu and Janowicz 2016). "

5.4 Conclusions

The case study aimed to show how CI resilience can be operationalised in a concrete urban setting. From the range of possible indicators to capture the key resilience factors (see Bruneau et al. 2003, and Figure 15,16), this case study has focused on the speed of recovery that is influenced by the accessibility using road transportation by fire brigades and rescue services (Figure 26) to access key infrastructure assets such as hospitals in a flood situation. Additionally, criticality assessment of key services such as fire burn stations has been used to illustrate how rare elements (burn stations) or rare service capacities (providing treatment for severely burned people) can become critical. As a contrasting example, a GIS assessment has been conducted for transformer sub-stations, which are rather frequent in a city area. However, it has shown that in a severe river flood, a great number of those stations might be exposed and based on this a blackout area zonation approach has been demonstrated. Criticality of assets, exposure zones and routing of emergency cars all are factors influencing the speed of relief and recovery and therefore, what is termed resiliency. However, there are a number of limitations mentioned in this case study and in order to capture the whole range of resilience parameters (Figure 16), more work has to be carried out.

The work presented in the case study is an insight into present, on-going research. The GIS analysis on resilience aspects of cities and its connections to their hinterlands with a focus on critical infrastructure is expanded on aspects of differentiation of routing and access to hospitals, refugee shelters and other important emergency management assets (Tzavella et al. submitted) **(P11)**. Within the research project "Critical Infrastructure Resilience – minimum supply concept" (CIRmin project), currently the capacities at city and rural community level to function under conditions of large-scale blackouts and failure of other vital infrastructure such as water supply are investigated. This adds to work conducted in a research project "KRITIS Kapa" that started to generate an overview on needs and limits of capacities of several CI stakeholders. However, the results of project KRITIS Kapa were classified, as were the results since they were regarded to contain sensitive information. Likewise, some results of another project were classified. The project, termed KritisKat, was developing methods for CI identification and a national priority list. Much of that methodology has been used in this work, but there is no official report that can be referred to our work yet. Data sensitivity constraints also limited the possibilities to illustrate the methodology in the case studies in this volume, for instance through the selection of point elements of the electricity grid we decided using. We did not use very rare and therefore especially critical infrastructure elements, for example, since such data could be misused. However, the case studies provide some insight into what can be analysed as CI in a concrete urban environment.

Main findings of chapter 5 'Case study'

Chapter 5 mainly contributes to the research question:

Techniques and applications

4. How can resilience be assessed in a case study?

-> Q4. Resilience can be assessed by applying the concept outlined in the previous chapter 4 at an exemplified analysis of resilience of critical infrastructure in Cologne. The rapidity of accessibility and limitations of resourcefulness and redundancies are shown at the example of how fire stations can serve hospitals in case of a severe crisis that results in impairment of road usability due to floods **(P10)**. Routing analysis illustrate how the rapidity of recovery is dependent on roads, flooded streets and affected assets (hospitals) as well as the critical infrastructure itself (electricity grid, fire brigades) are affected. In addition to a pre-existing river-flood zonation layer, a blackout zone is derived where the impact of flooding is possibly aggravated by failure of power supply.

Resilience is assessed by applying the concept with a GIS; gathering and overlaying flood zonation information with exposed assets of infrastructure such as electricity grid and road network. Using routing algorithms, distances between hospitals and fire brigade stations and time for reaching those facilities by car are computed and isochrones of reachability in two minute intervals provided. Different routing options are then differentiated including one-way streets, before and after a flood and this is analysed for hospitals as well as for refugee homes **(P11)**. Volunteered Geographic Information is further discussed to add vital information to advance the methodology in the future and specifically add participatory information by affected people to the risk assessment.

6. Synopsis and perspectives of an emerging research field

Research field domain

"Urban disaster resilience" is a sub-domain of urban resilience, which is a sub-domain of several domains such as urbanisation, global change, and others. However, within the specific focus of this volume, "urban disaster resilience" is mainly regarded as a sub-domain of what is termed here Disaster Risk Research, but what is more commonly known as Disaster Risk Reduction, or, Disaster Risk Science.

Neither urban disaster resilience nor Disaster Risk are accepted academic disciplines, such as Geography. However, they have gained wide interest amongst various academic disciplines.

"Urban disaster resilience" is in this volume further specialised by the connection with the topic "Critical Infrastructure", a topic triggered by political actions after terrorist' attacks within the USA, than spilled over to Europe after 1996, and was quickly picked up by academic studies.

From an applied perspective, the fields of "Disaster Risk Reduction", "Urban (disaster) resilience" and "Critical Infrastructure" are also part of what is termed security studies, risk management, or risk governance. At the political and administrative side, these domains are connected to various fields including civil protection, national and community security and safety.

Adopted research paradigm and concept

The resilience concept used in this volume mainly adopts views of social-ecological-systems research that includes perspectives of (general) system theory, hierarchy theory, complexity theory, and adaptive systems. There is also a connection to what is often termed a technical or engineering view on resilience. But also, action-theory from social sciences is important within "community resilience", too.

Resilience in this volume, however, itself is embedded within a Disaster Risk Management concept (DRM; related to Disaster Risk Governance) with a conceptual structure of underlying temporal phases before, during and after a crisis, which closely fits to the social-ecological-systems understanding of resilience. Apart from such life-cycle models, the DRM concept adopts a process view closely related to project management phases where resilience is one step within a process that includes stakeholder inclusion, communication, analysis, evaluation and action steps to be taken. DRM itself is part of security policy (and research) which itself contains not just the aspects of epistemic uncertainty, but also aleatoric uncertainty. However, security contains more than dealing with uncertainty of knowing, it also includes uncertainty about futures, preferences and distributions of societal values (Schwarz 1981). Within this background, urban resilience is just a tiny part, yet it offers a sound place-based context for addressing certain aspects of security, societal values and risk management goals as well. Critical Infrastructure and urban resilience in combination address several important aspects of current investigation; combinations of human and technical aspects, for example.

6.1 Synopsis of the work presented in this volume

Urban areas are structural and symbolic hallmarks of human evolution and development. On-going urbanisation processes and population growth are followed by an increasing awareness of disaster and crisis susceptibility. Increasingly, the concept of Disaster Risk Management analyses so-called natural hazards, man-made hazards, natural and man-made vulnerabilities in concert. Resilience is a recent paradigm shedding new perspectives on the overall goals of Disaster Risk Management (DRM), and stimulating the advancement of existing analysis concepts and tools. While urban resilience has become an accepted and widely applied field of research as well as of DRM actions, a number of research and action gaps remain that were addressed.*
This work is not a single study aiming at answering specific research questions of a single case only, rather, this volume aims at offering an overview on a broad interdisciplinary and multi-faceted field of research; urban disaster resilience and its specific interrelations with critical infrastructure. The main findings of each chapter have been summarised and described before; hence in this synopsis, the main findings will only be brought together once more to illustrate the overall picture, and not in detail.

The following key questions and accordingly, the main findings in this volume, are conceptualised after what Richard Feynman defined as the core content of science: a) contributing to the body of knowledge, b) techniques and applications and c) innovations (modified after (Feynman 2007).

Body of Knowledge

- What is resilience as a concept and how can it be assessed?
  Findings: In several publication we have shown what is specific about resilience as an analytic concept and how it can be integrated with existing hazard, risk or vulnerability concepts within the field of Disaster Risk Science.
- What is the resilience of a specific region and how can this be assessed?
  Findings: We have identified suitable research units and areas and provide an integrative concept that allows analysing different aspects of Critical Infrastructure and how it affects resilience and overall risk in this area.

Techniques and applications

- Which techniques such as methods of risk and resilience assessment can help to better understand urban disaster resilience?
  Findings: urban planning needs integrative risk management approaches that integrate DRR, CCA and Critical Infrastructure themes and methods. We have developed a stepwise procedure and concept for integration of those previously unconnected themes and shown its applicability in a case study.
- How can resilience be assessed in a case study?
  Findings: The resilience of infrastructure can be identified and improved by analysing sectors such as road network in conjunction with hazard scenarios such as floods or blackouts.
-

Innovations

- What is the novelty of urban resilience versus pre-existing concepts of disaster protection or sustainability?
  Findings: In several workshops, surveys and review publications we have established an overview on novelty aspects but also factor that hinder acceptance and distribution of resilience so far in German-speaking contexts. Our analyses show what might be overlooked or side-lined by an overly focus on cities and resilience. Alternative concepts such as vulnerability, or loss & damage have been critically analysed. Scientific tools and communication platforms have been developed that allow for analysing specifically urban disaster resilience.
- What can the topic and methodology of research on Critical Infrastructure (CI) offer for urban resilience assessments?
  Findings: Concepts and tools have been developed that allow for identifying CI and CI resilience. CI resilience has been shown to be a vital part of urban resilience and how it an be integrated with pre-existing concepts such as spatial risk assessments.

Contributions to research concepts and methods

The work in this volume includes as a main finding a suggestion for a concept for identification and ranking of societal values within risk management and specifically, for research of Critical Infrastructure. This is part of a procedural methodology to identify CI elements, processes and especially, the services provided to society. Also, specific indicators for measuring resilience of CI within urban areas are investigated concerning their usability and applied in case studies. Tools used in this volume are exploratory expert interviews and Geographic Information Systems (GIS).

Specific Innovations

The following aspects are not novel themselves, but within the specific perspective of this volume may contain aspects of innovation.

- Development a method for criticality analysis including identification of risk management goals and societal values **(P13, P5, P6)**
- Broadening the understanding of technical CI to an advanced and integrative understanding of CI services to human and society **(P13)**
- Critically investigating upcoming paradigms and outlining pros and cons of resilience and vulnerability paradigms **(P9)**, spatial vulnerability indicators **(P14)**, loss & damage as an alternative model to disaster prevention **(P7, P8)**
- Method for CI to be applied including the resilience concept in delineated urban areas in Germany – suggesting novel GIS applications for urban planners and disaster managers **(P10, P11)**
- Ex-ante assessment of resilience related to Critical Infrastructure in a case study using GIS **(P10, P11)**
- Novel empirical insights and documentation of integrative views of disaster researchers and practitioners over the range of past decades on the

development of hazards and DRM actions and acceptance of novel paradigms such as resilience or climate change **(P9, P18)**

- Contributing to knowledge management by generating the first comprehensive (natural and man-made hazards) overview on resilience and vulnerability studies in Germany, Austria, Switzerland and Liechtenstein **(P18)** and an overview volume of about 70 international authors working on urban disaster resilience (book forthcoming in 2017; **P25**)

Synopsis of case study

In the case study, the main purpose was to demonstrate how resilience can be operationalised by illustrating it in a chain of methodological steps, from risk management goal, over generic criteria to a case study utilising spatial data in combination with other auxiliary data. Despite increasing amounts of studies on this, still the application of resilience and what it offers in contrast to vulnerability studies, for instance, is much demanded, by researchers and practitioners alike (Fekete et al. 2014) **(P9)**. There are also major gaps in linking spatial assessment of vulnerable populations with service blackout areas and natural extreme events. Also, the vulnerability, but also capabilities of key health care facilities such as hospitals, key disaster risk management assets such as fire brigades and rescue services and key shelter areas are often lacking an explicit spatial assessment. Certain details of analysis have also to be advanced in the future by developing estimated parameters of driving speeds of cars and trucks through flooded streets, for example, or, gully lids floating in flooded streets, or, better estimates of blackout areas based on historic event documentation and approaches utilising non-sensitive open source data. Another field of current development is 'big data' (mass data exploitation) and social media exploitation. This is a window of opportunity to make it not just data extraction and exploitation but to enable the mobile phone users to feedback important information about evacuation routes, demands on baseline services and other relevant crisis and resilience aspects (Fekete et al. 2015)**(P12)**. While the ex-ante phase is naturally the most difficult since predictions about the future are almost always wrong, they are at the same time the most challenging and exciting but also necessary works of researchers in order to ameliorate societal crises and unrest. On the one hand certain avoidance of major accumulations of risks can be planned, for example, keeping densely populated city areas in high risk zones or the development of infrastructure hubs without a risk or resilience plan. Still, certain unexpected events will be unavoidable and unforeseeable, but to at least conduct the necessary 'homework' and research will also help during and in the aftermath of a crisis when often questions about liability, causes and responsibilities are put forward. Especially within the CIP topic, this often puts researchers into a dilemma; due to the threat of attackers who might read scientific papers or hack themselves into data bases – should gathering and aggregating data on sensitive infrastructure element locations be avoided? When security of data becomes too complicated and methods of attackers become too efficient, should researchers avoid a topic? As an answer to this, a balanced approach is aspired; data in our work is based on public data and on elements that are believed by the author not to be in the highest risk category in terms of possibilities for misuse.

Other researchers have in former times published on the most efficient ways to attack Great Britain with nuclear bombs, for example (Openshaw and Steadman 1983). But nowadays we must on the one hand use the methodology at hand but at the same time consider ethics and unintended side-effects even of seemingly unproblematic research on natural hazards (as compared to nuclear attacks). However, even in research on river-floods, strong opposition was experienced to explicit illustrations of flood risk and vulnerabilities of counties, for example (Fekete 2012b) **(p14)**. The main finding here is to be more aware of user's expectations but also to remain to some level independent from interests of users as a researcher. Therefore, this field of spatial risk and resilience assessments is regarded as an important future field of research which also still advancement in identifying how and which information will be acceptable by the users and other stakeholders. And also, which demands and concerns, of security and data privacy for example, need to be considered and integrated into a knowledge management of urban disaster resilience.

Limitations of this work are due to only one city being analysed and due to the still exploratory character of the case study assessment. So while the concept in chapter 4 is per se meant to be transferrable to other cities and local contexts, the application at other case study sites is still missing. Also, evaluations and validations are still not sufficient to describe how transferability could take place – limitations are not known and documented well enough yet. While some for of evaluation has taken place, by the energy grid operator regarding the blackout area and by the iscochrone specialist, and both were positive about the assessments, still more assessments of a great number of other Critical Infrastructure and risk factors such as population at risk must follow and more evaluation studies. As indicated below, the focus on big cities alone is not sufficient and urban resilience must also expand to capture urban rims, smaller cities and other areas important to capture human beings and assets at risk.

6.2 Additional Perspectives for this field

While the previous summary describes the main implications for further research based on the case studies presented in this volume, the following section will highlight future research areas based on the wider field of urban resilience and critical infrastructure.

Integrative resilience concepts

At the moment there is a great trend in theorising research in many areas linked with urban resilience and critical infrastructure. Sustainability has already been an integrative concept bringing disciplinary skills and demands from different sectors together such as environment, urban planning, infrastructure and economic development, new energy concepts but also environmental protection and risk avoidance. Disaster Risk Reduction and resilience are in many respects just follow-ups in a similar vein, adopting similar theoretical concepts such as ecological systems and landscape ecology, political ecology etc. There are certain differences in focus and detail, for example, while risk researchers regard density of urban areas with agglomerations of people and values at stake as a risk factor, sustainability stimulates a policy of densification of settlement areas in some respects, when it meets counter-peri-urbanisation and anti-urban sprawl, for example.

Yet there is a great trend for convergence and integration of concepts. This is partly driven by the recognition and experience of work in an applied field with targeted audiences. The audiences and 'end-user' of sustainability as well as risk and resilience concepts often are cities or decision-makers in certain organisations and companies within urban areas. They are facing resource and budget constraints and ever-novel regulations and guidelines to be implemented; be it fire safety, health safety and environment regulations or climate change adaptation. While some of these upcoming trends also offer new budget lines and windows of opportunity to change and modernise their own system and resource allocation, still it remains a major challenge and burden, especially for small and medium enterprises and institutions. The challenge is to allocate personnel, time and infrastructure for tasks such as implementation of a European flood risk guideline, even when no major flood occurred in a town for decades. The same is true for implementation of worker safety or fire safety in buildings. It is therefore no surprise when neglect is a reaction to novel concepts to be implemented by external requirements when the real challenge for an urban area is economic prosperity or even survival,. The same can be stated for the people and many institutions in such a settlement. For all these reasons, integrative concepts are not just a trend to sustain over the coming decade because of scientific trends in fostering theorisation of traditional fields such as ecology, geomorphology or hazard research. It is also a demand of convergence of novel concepts with existing concepts for resource constraints on the end-user side.

Therefore, this volume presents topics concerning the integration of urban resilience with the field of critical infrastructure. There might be an increase in research in the coming years, not just because political programs and international agendas such as the Sendai Framework adopt it, but because the problem range of urban areas integrates natural as well as man-made hazards with demographic, societal and economic change. The following figure (Figure 30) is just an example how in this volume different aspects could be brought together.

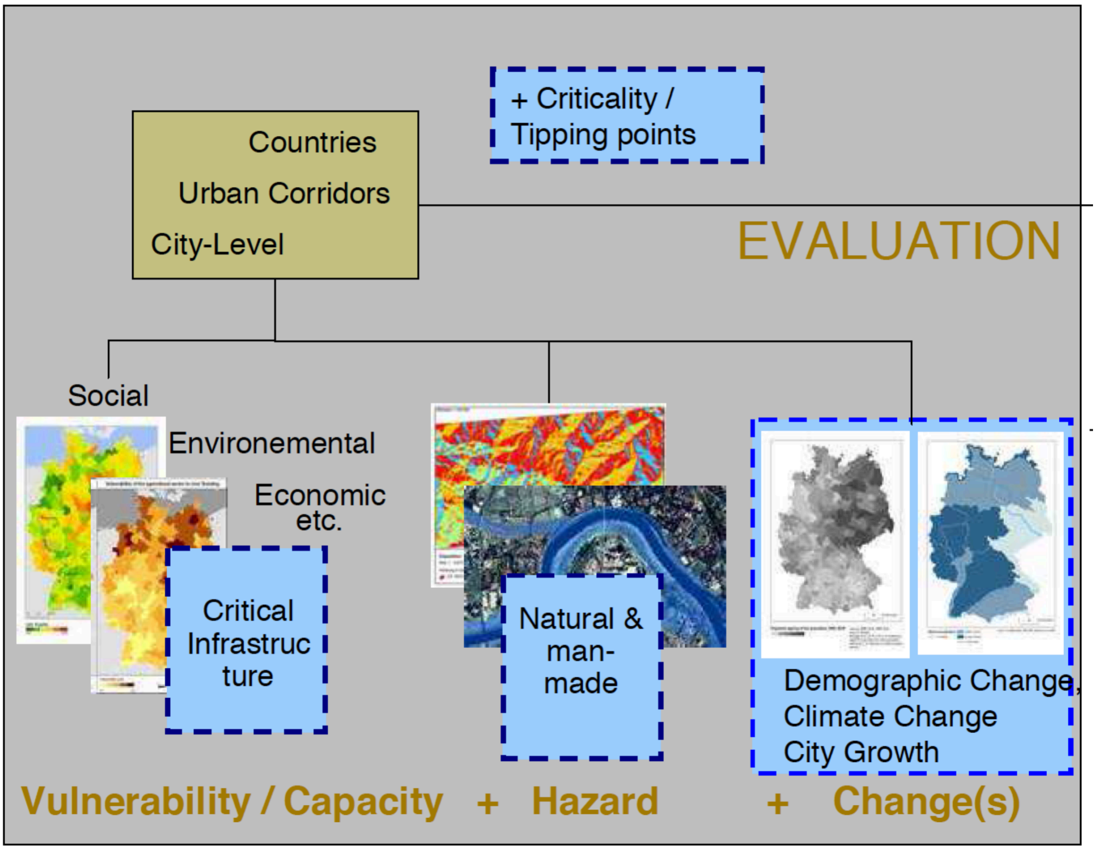


Figure 30 Outlook on the integration of different aspects of vulnerabilities and capacities of an urban area under influence of/towards hazards and changes (Source: author)

Contributions to disaster risk management and governance

At the DFG-NSF conference "Reckoning with the Risk of Catastrophe" in Washington DC in October 2012, the importance of trans-disciplinary research and transatlantic collaboration was stressed. There is an increasing demand to think outside of the box when it comes to complex, uncertain and highly interdependent and cascading disaster and risk events. This demand of widening perspectives has come from scientists and decision-makers, and stretches the boundaries of the traditional fields and disciplines they are educated in. There is an increasing recognition that there are limits to the level of safety and security that any organization, institution or individual can provide. Therefore, many development organizations such as 'Engineers Without Borders' have recognized the importance of alternative approaches to maintaining security. Rather than fearing discussions of failure, these innovative organizations are using honest assessments of past failure as springboards to smarter and more efficient development work. Important topics include: Letting failure happen, flexibility, the importance of alternatives to traditional approaches such as protection, risk and vulnerability reduction, and top-down security.

Additionally, state-of-the-art insights that have pushed boundaries in the area of disaster risk management have been gathered at other recent conferences. For instance, at the Keystone Conference hosted by the United Nations University and MunichRe Foundation in October 2012 in Bonn, Germany, advancements in the fields of risk and climate change in relation to the IPCC negotiations in Doha were discussed. In such forums, trans-disciplinarity and moving beyond recent paradigms of protection, top-down security, and vulnerability and resilience conceptualizations were key topics being discussed. A new topic, Loss & Damage, emerged and we have contributed to it with a survey amongst peers and identified no uniform opinion on it it such an early stage, however, some reserve to switch to an novel concept when resilience is still not put into practice yet (Fekete & Sakdapolrak 2014) **(P7)**. We have then accompanied the assessment of loss & damage with a conceptual reflection on possible side effects of introducing such a concept (Wrathall et al. 2015) **(P8)**.

Based upon observations described above, the following sections will formulate some selected research questions for future research.

Urban disaster resilience has been hyped in the U.S. and Germany, for example. Despite its importance as an area of research and management, it continues to be underdeveloped in many areas. For example, place-based disaster assessments and measures often overlook temporal aspects, as well as second order effects of disaster and inter-linkages of networks and assets situated far beyond individual cities or other administrative areas (Fekete 2012b) **(P14)**.
On the one hand, "the citizen" is more complex in our globalized world than assumed in semi-quantitative models; many commute to work or to home, families are often separated by distance but continue to maintain telecommunication, new non-traditional social networks are formed, etc. On the other hand, localism (local context) is an important factor to consider in sustainable and responsible awareness of personal environments. Sustainability strategies must find a nexus between individual habits and the residential area, infrastructure and ecosystem services. The focus on one region is limited, however, when critical infrastructures and other forms of social and ecological dependencies are not taken into account. This means that resilient cities must develop an awareness of their surroundings and interdependencies with the hinterland along with its connections with its nearest neighbouring town. In addition, research must not stop at the status quo it must also consider transformations in society and what this offers to complement the dynamic picture of resilience.

Key questions for future research

- How can the concept of resilient city be advanced?
- How can sustainability strategies incorporate the people, the area AND social networks?
- What are innovative measures for the protection or transformation of communities?

Moving beyond the hype around resilience

Recently, resilience is a major paradigm in disaster risk and climate change science, but also in urban planning (BBSR - Bundesinstitut für Bau- Stadt- und Raumforschung 2013), spatial planning (Kilper 2012) or technology and engineering (Thoma 2014). In the coming years, discussions can be expected about the benefits and ways to operationalize resilience, as well as pitfalls and mal-resilience to gain ground. Similar

to the cases of recovery after the Indian Ocean Tsunami 2004 or Tropical Storm Sandy in 2012 disasters, recurring doubts about rebuilding and bouncing back become salient.
Yet, beyond a mere conception of 'bouncing back', resilience is currently thought to include the ability and processes to 'bounce forward' as well (Manyena, et al. 2011). 'Transformations' and changes are key terms in many sciences and management, even beyond disaster, risk or climate change communities. However, mal-applications of transformative thinking and negative side-effects may also occur, such as overly rapid or unsustainable innovations and changes that serve only certain interest groups. A thorough investigation would highlight both the pros and cons of resilience and sustainability, and that this type of analysis is long overdue, especially in order to provide better guidance for scholars and decision-makers.

Key questions for future research:

- What is the next trend after the trend – and how sustainable does innovation need to be in DRM?
- Which are useful structural and non-structural sustainable recovery strategies?
- What are possible mal-resilience applications and how can they be identified?

Incentives for the critical infrastructure and urban resilience nexus: Minimum supply concept

Societal relevance: While there is ample research and DRR measures being taken to prevent certain natural and manmade disasters, the second order effects, cascading effects of infrastructure affected by such initial disaster impacts, are still lacking research and application. While populations are already at risk by the initial impacts of a riverine flood, for example, the secondary effects of lack of energy, water and food supply can aggravate the situation for survival, health and recovery significantly.

End-user relevance: Much focus and experience exists for everyday emergencies and standard risks such as certain recurrent river floods or certain industrial accidents amongst civil protection agencies such as fire brigades, rescue services and disaster risk managers in companies and public administration. However, for the case of rare events there exist few management plans and experience how to deal with unknown events, or in novel contexts, situations and with unknown magnitudes, frequencies or periods and qualities (Fekete 2011) **(P13)**. There are certain constraint factors in risk governance that vary much between countries or even within a country's administrative areas. Examples for such constraints are lack of resources, linked to lack of political and public awareness and experience with major crises. Another constraint is that liability and responsibility for disaster alert phases is hardly known and exercised in real situations, as is the case for many industrialised countries in Europe.

Conceptual relevance: Within common risk analyses there is a lack of understanding what novel applications and perspectives are provided by the resilience concept. One major shift in focus, is a perspective on the recovery phase, rather than identifying possible risk impact paths, vulnerability or criticality factors in a static picture. The idea on focusing specifically on a minimum supply situation touches upon a selection of resilience aspects, some of them certainly already been conceptualised also under a civil defense, disaster risk or risk management perspective in past decades. In the state-of-the art chapter, reserve storage and existing resilience by design measures will be outlined as well as emerging minimum or baseline security concepts.

The main change in a minimum or baseline perspective is acknowledgement that all previous assumptions of hazard and disaster prevention have already failed. This offers new paths for focusing on not only responsibilities and effectiveness of measures in DRR until the event phase, but also on the immediate crisis reaction and following recovery phases. This will also provide new conceptual linkages between what is termed risk management (ante disaster) and crisis management (reaction and post disaster).

Context and contribution to (German) geographical risk research

The work in this volume addresses different streams in the discipline of geography. Within the line of geographical risk research, the aspects of recovery of settlements after disasters has been a topic in the work of Robert Geipel on the recovery of the region of Friaul in Italy after an earthquake in 1976 (Geipel 1982). While it was not termed resilience at that time, the recovery of housing and population including the transformation of the small cities and rural areas affected after rebuilding as well as the socio-economic conditions in the area could nowadays be framed under vulnerability and resilience concepts.

There is a large overlap of current disaster risk and resilience concepts with ecological resilience (Holling 1973), socio-ecological systems (Gallopin 2006), in general, system's theory (Bertalanffy 1968), human ecology (Hewitt 1983) and inter- and transdisciplinary landscape studies (Tress et al. 2003). Here, strong links are visible to traditions in geography, such as system theory approaches in physical geography (Chorley and Kennedy 1971), but also spatial organisation (Abler et al. 1971) and urban systems (Berry and Horton 1970). Interestingly, many of the main innovations in this field in relation to geography date back to the 1970s, a time, when vulnerability and resilience also emerged within disaster risk research (Hewitt and Burton 1972; Hewitt 1983) and since then exert an important paradigmatic influence on the field (Fekete et al. 2014).

Urban growth and change detection also by use of remote sensing (Glaser and Dech 2013; Baumhauer 2009) and in combination with GIS (Conrad et al. 2015) is another important area where geographical risk research produces important baseline data on exposure to natural hazards. Urban resilience especially with links to megacities is a common topic in geography (Kraas et al. 2014) and includes conceptual framework research, quantitative as well as qualitative methods (Butsch et al. 2009).

There is also a strong linkage to operationalization and measurement approaches conducted by usage of resilience indicators to spatial approaches used in geography but also neighbouring disciplines such as spatial planning. For example, a session at a geographical congress (2015 German Congress of Geography in Berlin, hosted together with J. Birkmann, entitled: Die 'Measurement of the resilient city under signs of Climate

Change and other natural extremes' (Vermessung der Resilienten Stadt im Zeichen des Klimawandels und anderer Naturextreme) was a starting point for several activities in this field, including an edited book (Eds. Fekete, A & Fiedrich, F.) **(P25)** with more than 60 authors on "Urban Disaster Resilience and Security" aspects, due to be published in 2017 by Springer.

Secondary hazards and cascading effects of natural hazards such as landslides (Dikau et al. 1996) affecting and damaging critical infrastructure such as transportation ways are another area of research (Jäger et al. 2015; Klose et al. 2014) which is used in a similar way in this volume to analyse the interrelation of floods and electricity with a GIS. The ensuing questions of societal relevance and costs of these disaster impacts in industrialised countries (Thieken et al. 2015) also related to infrastructure (Klose et al. 2014) is an aspect not addressed in this volume, except for establishing a methodology to prioritise economic versus humanitarian and other general strategic goals and values in civil protection (Fekete 2012) **(P5)**.

The work in this volume integrates with key research on fostering deeper understanding of effects and damages of natural hazards such as floods on affected communities, housing and perceptions but also costs and adaptation measures (Thieken et al. 2014). The work in this volume uses methods and concepts of risk assessments used in contexts to natural hazards and integrates them with critical infrastructure research and specifically, resilience of critical infrastructure. While resilience is still a word used cautiously in lessons learned studies after disasters in Germany (DKKV 2015) there are certain research lines on capacities of communities, vulnerability indicators and critique on them that also cover resilience (Kuhlicke 2013; Lorenz 2013). Critique and self-reflection on vulnerability indicators and how to progress to resilience indicators is also important part of work in this volume (Fekete 2012b) **(P14)**. On the other hand, practical solutions have been sought to measure and monitor vulnerability and resilience in context to urban areas and critical infrastructure. Such risk assessments with spatially explicit risk zonations are a traditional field of geographical risk research. Such assessments increasingly do not serve themselves only, but are tied into an integrative management context, where they can help decision-makers on risk prioritisations (Birkmann 2013) and serve later also as baseline information for Early Warning Systems for natural hazards (Glade and Nadim 2014).

The research on critical infrastructure touches several fields in geography, such as infrastructure sectors ranging from energy, water, food, public administration to several other fields covered mainly in human geography, but extends also to infrastructure-related dependencies of e.g. cities with technical and logistic networks (Rauh 2002) and secondary hazards such as distribution of diseases (Kistemann and Exner 2014). Certainly, there are many relations to urban geography (Hofmeister 1999), but in its broadness, this is beyond the scope of this volume. Specific relations of urban contexts to history, climatic and ecological settings (Glaser and Schenk 2004; Schenk et al. 2007) would be worth considering in flow-up studies.

While the case study example in this volume is from a selected German city and context only, it is important to outline the relevance of international research, especially given the growing role of international research and policy fields such as UNISDR but also given the global interrelations of supply chains and climate extreme effects, but also international humanitarian assistance and development cooperation. Geographical risk research in Africa (Baumhauer 2009; Sponholz 2004) or in development contexts in general provides important conceptual advancements of 'riskscapes' and underlying socio-economic drivers of vulnerability and resilience (Müller-Mahn 2003; Blaikie, et al. 1994). Also, areas such as geomedical research are relating traditional disease research to physical environmental conditions (Hartmann et al. 2014; Renaud et al. 2015) or to spatial assessments using remote sensing (Walz et al. 2015). In order to broaden the scope of the work on resilience and interlinkages between man-made and natural risks, also two alumni seminars (DAAD) were conducted with participants from 19 countries in Africa, Asia and Latin America on the topics of "Coping with Disasters and Climate Extremes" (04-08 November 2013 – in Cologne & Bonn) and on „11 Years After the Indian Ocean Tsunami 2004 – Lessons of Disaster Recovery, Rehabilitation and Resilience", (9.-13. November 2015 in Cologne, Germany). The 2015 seminar explicitly focused on resilience in terms of recovery, while the 2013 seminar contributed to an understanding of climate change and extreme event relevance in different countries globally (Norf et al. 2014; Grinda et al. 2015). One finding is the need to conduct more research not just on risk assessments or resilience measures per se, but to assess their effectiveness and persistence even five or ten years after the disaster event to assess how sustainable such measures are (Stephan, et al. 2017) **(P15)**. This shows up an important outlook and impetus for continuing the work presented in this volume; advancing research on resilience of critical infrastructure on validation and evaluation studies, longitudinal and repeating studies after time phases of 5 and 10 years. Resilience studies need validation of quantitative approaches (e.g. following previous work on river-floods Fekete 2009) but also evaluations of effectiveness, efficiency, acceptability, persistence and many other aspects of both quantitative as well as qualitative studies by asking researchers as well as practitioners, donors and supported population (Stephan et al. 2017).

There are traditional arguments between an almost stereotypical division of human and natural geography, and certain mediating approaches (Weichhart 2005). However, recently natural and man-made hazards and risks increasingly are investigated together. The growing systematic and theoretical foundations of such inter- and transdisciplinary research help to advance this perspective. Geographical risk research has matured and integrated more and more disciplines over the years. Our work is in this line of multidisciplinary work integrating work on natural as well as man-made catastrophes (Felgentreff and Glade 2008). The work in this volume, especially within workshops, the Atlas project (details in later section) but also sessions at geographical conferences (2015 DKG in Berlin, session hosted together with G. Hufschmidt, entitled: Wissensvermittlung und -nachhaltigkeit in der Geographie: Resilienz und Verwundbarkeit als Trends der Risikoforschung) also links to knowledge management (Hufschmidt et al. 2016) **(P21)** and education in geography dealing with risks and hazards (Köck 2012; Schmidt-Wulffen 1982). Moreover, in publications (Fekete et al. 2015) **(P12)** and at workshops (as advisor to the INQUIMUS workshop series in Salzburg 2014, Bolzano 2015) it was sought to bridge the gaps between qualitative and quantitative approaches, for example, in "measuring" vulnerability or resilience.

However, especially for the work presented in this volume is might rightly be argued that this is not science (in the sensu strictu as natural sciences), rather research. The proper description could therefore be Disaster Risk Research.

The work in this volume however matches several lines of how science is defined (Feynman 2007); a) enhancing knowledge by the work on knowledge management with the workshops and the Atlas VR. b) Creating new techniques by conceptual advancement of criticality identification and prioritisation method (Fekete 2011, Fekete et a 2012) **(P13, P6)**, ranking of overall values and protection goals (Fekete 2012, Fekete et al. 2012) **(P5, P6)** and operationalisation of resilience by application in a GIS (case study Cologne) **(P10, P11)**. Here, also a strong conceptual link to geography can be established by using the generic criticality criteria of spatial, temporal and quality contexts (Fekete 2011) **(P13)** that match to a Critical Infrastructure context as well by identifying, for example, the most critical asset in a region by the generic criterion of maximum number of assets affected in minimal time and affecting a specific quality of what the infrastructure service (such as drinking water or fire fighting water) offers . And finally, c) finding out something new. The innovation aspects in this volume are very limited (see summary at beginning of this volume). While operationalisations of resilience in context to urban areas and critical infrastructure are rare for a German context, this is far from being called a novelty. It is a key characteristics of science that real novelties are rare, and here, this volume is no exception.

However, as a summary, this volume addresses and touches a number of fields in Geography, but risk research will always remain a sub-category, rightly so, since there are many more topics that deserve attention.

This short section did not capture all relevant researchers in the field of geographical risk research let alone geography. It also did not mention any of the key researchers in neighbouring disciplines. The purpose was rather to highlight certain aspects in geography related to this work.

Regarding case studies and research areas, the near future will likely see more specialisations of approaches, and urban disaster resilience is just one among many. In a geographical sense, it is likely that new types of 'resilience-scapes' will be researched, such as river deltas (Kuenzer et al. 2015; Wolters and Kuenzer 2015), mountainous regions such as Himalayan cities (Shankar 2014), aerotropoles (Kasarda and Lindsay 2011) and a shift from megacities to also the second cities in line, small and medium cities (Birkmann et al. 2016) and urban-hinterland interactions, as also stressed out in this volume. Regarding time, databases and scopes will extend into the future as well as into the past, even pre-industrial settlements are already analysed using resilience and vulnerability concepts (Curtis 2014). There is also an opportunity to explore the popular topic of abandoned or lost cities, ghost towns (De Tocqueville 2015) and deriving criteria to explain resilience or mal-resilience.

Final conclusion – urban disaster resilience and critical infrastructure - a new thematic research field

It is one ambition in this volume to show applicability of urban disaster resilience assessment by utilising spatial risk assessments of critical infrastructure. However, the bigger ambition is actually to illustrate an upcoming new thematic field of risk and security research; urban disaster resilience and critical infrastructure. Strands of research have long existed, but run separately; critical infrastructure protection from 1996, critical infrastructure resilience from around 2005, with a focus mainly on attackers and stability and defence of technical components. Disaster risk research, with different origins and streams since 1945 and even before, converging into Disaster Risk Management and –Reduction, advanced by the conceptual trend driver, resilience. Infrastructure has always been a topic addressed in emergency or disaster risk management, and in risk analyses, be it as assets exposed to hazards, crucial lifelines to re-establish after disaster, or enablers of logistics for recovery. However, there is much more potential in merging both topics than is even layed out in the current Sendai Framework. Critical Infrastructures are essential parts of an urban environment, hallmarks of urbanity itself, but they are not merely technical assets that need to be protected. An integrated thematic field of urban disaster resilience in combination with critical infrastructure not only overlaps infrastructure as another layer over other risk or vulnerability or resilience indices. CI themselves must be comprehended as more than technical elements, since it is basically the services and goods than humans need and get accustomed to at such degree it has created dependencies and cascading effects when interrupted. CI are themselves also composed by more than technical assets only, they consist of human staff, regulations, quality and more. And while traditional disaster risk assessments only capture infrastructure as another damage layer to be added to the equation, CI are in fact aggravators of cascading risks, but at the same time enablers of resilience themselves; affected by hazard impacts but also delivering key services such as power, water, information and many more resources an urban society is not just dependent on in daily life but also in severe crisis situations even more. As a thematic field, this merger mainly helps to conjoin research perspectives and methods such as technical with organisational, planning with spatial, temporal and network awareness. CI especially offers advancements of risk assessments by a focus on integrative risk management concepts including formulations of risk management goals, and pre-prioritisation of research efforts using criticality criteria and assessments. CI carries certain methods from complex adaptive systems but also failure mode and normal accident theory into disaster risk research often keen on identifying thresholds. And while spatial vulnerability assessments often reveal static imprints, CI resilience specifically focuses on temporal aspects such as rapidity of repair. And while vulnerability and risk are often indicating corridors or spans of possible distributions of factor loads from a relative minimum to maximum value distribution, CI offers thresholds and criticality levels.

Urban areas are a recent focus that aims at integrating different strands of hazards and risks efforts to be carried out at a specific regional area. This is one reason to select the urban topic. However, urban-rural connections are just as important as big cities, therefore, 'urban' has to be understood as resemblance of human civilisation assets and habitats exposed to hazards and threats, not just represented by mega cities, but by small and medium sized cities, urban rims, villages and any type of settlement and connections between them. Urban activity includes interaction with hazards, stressors and threats as well as opportunities and chances of many sources. Therefore, this is an integrative thematic topic also in the sense as it truly merges man-made, technical, and natural hazards and risks.

Figures

Figure 1 Guiding sheet and structural flow chart of the publications by the author relevant for this volume (Source: author)........ 8
Figure 2 Survey results for the question after the main benefits of using the terms resilience and vulnerability (Source: Fekete, Hufschmidt, Kruse 2014: 12) (P9) 15
Figure 3 Survey results for the question after the main problems and challenges of dealing with resilience and vulnerability as a term (Source: Fekete et al 2014: 13) (P9)........15
Figure 4 Reponses to the question on alternative terms to resilience and vulnerability (N=30, Source taken from: Fekete & Sakdapolrak 2014: Int J Disaster Risk Sci (2014) 5:88–93: 89) (P7)........17
Figure 5 Reponses to the question on loss & damage being an alternative to resilience and vulnerability (N=38, Source taken from: Fekete & Sakdapolrak 2014: Int J Disaster Risk Sci (2014) 5:88–93: 89) (P7)........17
Figure 6 Atlas of Vulnerability and Resilience title page and example of case study sheet (P18)........18
Figure 7 Development of resilience strategies in the wake of disastrous events (Bach et al. 2013) (P4)........22
Figure 8 Risk and crisis management disaster time phase cycle in German national civil protection (Fekete and Walter 2011) (P23) 29
Figure 9 The risk management project process cycle in modified version (Fekete, et al. 2012) (P6)........30
Figure 10 Multiple hazards and threats on the left side and interdependencies with multiple impact layers on the right side (in: Fekete, Lauwe, Geier 2012 Int. J. Critical Infrastructures, Vol. 8, No. 4, 2012: 339) (P6)........31
Figure 11 Schematic illustration of different phases of hazards impact chains and interdependency reactions (Source: author) 31
Figure 12 System or object process path (Source: author) 33
Figure 13 Resilience Process Model (Source: author)........34
Figure 14 The 3 Impact layers (3Il) framework (Source: author)........38
Figure 15 Vulnerability and resilience factors separated into differing factors that can be analysed with spatial information. The map shows examples of transformer sub-stations and an extreme flood scenario (HQ500 including failure of flood defense). (This figure, in similar layout, is also in (Fekete and Hufschmidt 2016) (P18) 41
Figure 16 Conceptual overview on indicators important to capture resilience, for example, for urban areas (Source: author) 42
Figure 17 First step in CI identification – value affected by possible failure (in: Fekete Lauwe Geier 2012) (P6)........47
Figure 18 Second step of CI identification – ranking of CI using time factors (Fekete et al. 2012: 346) (P6)........48
Figure 19 Example for resulting ranking according to time until failure will impact a CI service (Fekete et al. 2012) (P6)........48
Figure 20 Third step in CI identification – criteria for identification within a specific regional context, e.g. a city (Fekete et al. 2012: 347) (P6)........49
Figure 21 Degrees of criticality derived after a simplified decision method for sub-national level (Source: author) 49
Figure 22 Three basic steps of the model to analyse critical infrastructure as parts of resilience of a place of investigation (for example, a big city) embedded into a risk management process 51
Figure 23 Conceptual and methodological steps applied in the case study (Fekete et al. 2017) (P10)........54

Figure 24 Exposure of hospitals and fire stations to an extreme flood scenario (named HQx; HQ500 including failure of flood defense and groundwater intrusion) (Source: Fekete et al. 2017) (P10) 57
Figure 25 Estimation examples of possible impact area of blackout (Source: Fekete et al. 2017) (P10) 58
Figure 26 Visualization of shortest path routing from the closest fire stations (red diamonds) to the flooded hospitals (triangles) using as a time scaled cost barrier the flooded area (delay of emergency response due to reducing of speed increased driving time). (Source: Fekete et al. 2017) (P10) 59
Figure 27 Map showing the locations of flood-exposed shelters (yellow dots) and hospitals (triangle) with respective numbers of beds per location. (Source: Fekete et al. 2017) (P10) 59
Figure 28 Quickest routing paths recommended for timely emergency response aiming at assisting the affected from the flood hospitals before (left) and during the extreme flood scenario (right). Source: Tzavella et al. (under review) (P11) 60
Figure 29 Isochrone polygons for 6 and 10 minute travel times during the extreme flood scenario with the restriction of the one way roads. Source: Tzavella et al. (under review) (P11) 61
Figure 30 Outlook on the integration of different aspects of vulnerabilities and capacities of an urban area under influence of/towards hazards and changes (Source: author) 71

Tables

Table 1 Overview on publications relevant for this habilitation (target requirements) 5
Table 2 Additional publications relevant for this topic 6
Table 3 Critical infrastructure sectors in Germany (Source: www.kritis.bund.de, accessed 10.3.2016) 20
Table 4 Department of Homeland Security: Critical Infrastructure Sectors 20
Table 5 Risk handling types, from control over management to tolerating risks (Fekete 2012: 69) (P5) 32
Table 6 Infrastructure components (Fekete 2011: 17, P13) 36
Table 7 Generic criteria for Critical Infrastructure identification (Fekete 2011: 20) (P13) 37
Table 8 Placement of resilience within the specific time phase of recovery 43
Table 9 Further differentiation of 'Abilities' at the example of resilience 45
Table 10 Example of a Critical infrastructure national priority list (Fekete 2011: 21) (P13) ..46
Table 11 Step A. Framing the concept and overall approach of resilience embedded in risk management 52
Table 12 Step B. Identifying conceptual components of vulnerability and resilience 52
Table 13Step C. Identifying conceptual components of critical infrastructure 52
Table 14 Assessment steps carried out in the assessment (Source: Fekete et al. 2017, P10) 55

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