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Chapter 5

c0005 Vulnerability Assessment to Heat Waves, Floods, and Earthquakes Using the MOVE Framework: Test Case Cologne, Germany

Torsten Welle*, **Yaella Depietri***,‡, **Marjory Angignard**†, **Jörn Birkmann***, **Fabrice Renaud*** and **Stefan Greiving**†

**United Nations University, Institute for Environment and Human Security (UNU-EHS), Bonn, Germany, †Institute of Spatial Planning, Technical University of Dortmund, Dortmund, Germany, ‡Institut de Ciècia i Tecnologia Ambientals (ICTA), Universitat Autònoma de Barcelona (UAB), Barcelona, Spain*

Chapter Outline

Assessment of Vulnerability to Natural Hazards. http://dx.doi.org/10.1016/B978-0-12-410528-7.00005-9

s0010 5.1 INTRODUCTION

p0010 Vulnerability assessment is an important first step toward effective risk reduction and climate change adaptation. Only if the population and decision makers know where and how vulnerable the system is and which social–economic, physical, and environmental factors play a major role in it, adequate measures can be implemented to reduce vulnerabilities to hazards and to adapt also to climate change. This study contributes to two different domains: primarily the scientific area, since it joins the research line of practical measurement approaches of vulnerability and disaster risk reduction (Maskrey, 1984; Chambers, 1989; Pelling, 1997; Cardona, 2001; Birkmann, 2006; IPCC, 2007); and secondly the policy area as this study provides information of the spatial distributions of vulnerability of the Cologne urban area to different natural hazards upon which the authorities need to take actions. The study is in this way in line with the objectives of the "Hyogo Framework for Action 2005–2015" which identifies risk assessment, monitoring and early warning as a current gap and challenge and which also calls for an increase of the "reliability and availability of appropriate disaster-related information to the public and disaster management agencies in all regions" (United Nations, 2005).

p0015 Vulnerability assessment needs to be based on a systematization and conceptualization of vulnerability describing the main linkages between the different components of risk (Downing, 2004). The MOVE framework (see Birkmann et al., 2013) was used as a conceptual framework in this study and its applicability was tested through assessing the vulnerability of the population of Cologne to the most relevant three hazards which affect the urban area. This paper presents the assessment of social vulnerability toward heat waves and floods on city district level, with some results for the environmental dimension of flood risk, as well as an approach to assess the institutional vulnerability of Cologne to earthquakes.

s0015 5.2 NATURAL HAZARDS WITHIN THE STUDY AREA

p0020 The Cologne urban area is situated in central-western Germany at 50°52′ North and 7°05′ East. It lies in the Federal State of North Rhine Westphalia (NRW) along the river Rhine (see Figure 5.1). The city is located along the Cologne

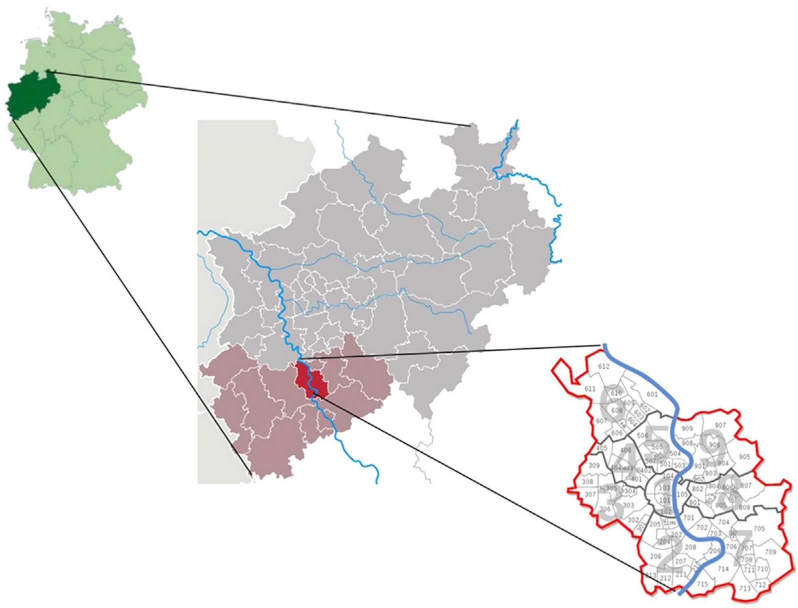

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FIGURE 5.1 The federal state of NRW situated in Germany (upper left) and the state of NRW including the Cologne urban area (highlighted in red).

Bight which is an orographic depression between the central German uplands, in the southeast, and the German lowlands, in the north. The Cologne Bight forms a plain, geomorphic delta which reaches to the northwest and slopes toward the lower Rhine lowlands. It is surrounded by the *Bergisches Land* in the east and the *Siebengebirge* in the south. The study area has a temperate-oceanic climate with relatively mild winters and warm summers. The average annual temperature ranges between 9.5 and 10.5 °C, and the average annual precipitation ranges between 750 and 900 mm (Kuttler et al., 1997). Cologne is the largest city in NRW and within the Rhine-Ruhr Metropolitan Area with around one million inhabitants and the fourth largest city in Germany. The city is divided into 85 city districts which are further subdivided into 370 city quarters. From a socio-economic point of view, the vast majority of the lowest status neighborhoods are clustered into two parts: the larger one is located on east side along the river Rhine and just beyond, and the second one is located in the northwestern part of the city (Wolf, 2002). The districts with the highest social status are more dispersed but mainly located at the borders of the city (Wolf, 2002).

p0025 Heat waves, floods, and earthquakes are the main hazards that have affected the city in the past and can potentially affect it in the future. Heat waves can lead to major threats in densely populated cities, also in northern Europe, as happened in the 2003 extreme heat summer event, and might become more frequent due to observed and projected increase in the frequency and magnitude of warm daily temperatures (IPCC, 2012). Flood is the second hazard being

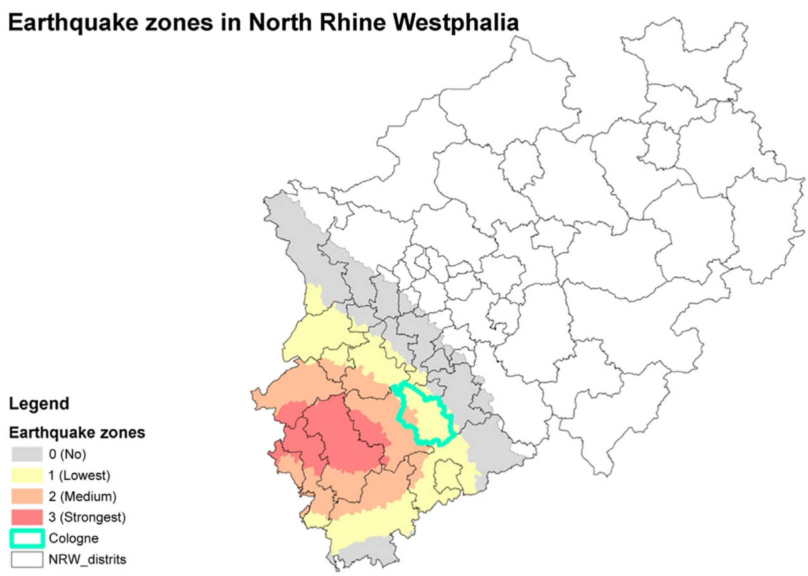

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FIGURE 5.2 Different earthquake zones in NRW and highlighted the administrative unit of Cologne. The different earthquake zones represent the ground acceleration (a) and thus intensity intervals (I) of earthquakes according to the European macroseismic scale (EMS): Zone $1=a=0.4\,\mathrm{m/s^2}=6.5\leq I<7$; Zone $2=a=0.6\,\mathrm{m/s^2}=7\leq I<7.5$; Zone $3=a=0.8\,\mathrm{m/s^2}=7.5\leq I$ (DIN 4149). *Own illustration based on data from the Geological Survey in NRW.*

considered as it has a long history of impacts in Cologne crossed by the largest river in Germany, the river Rhine. The city is also at risk of earthquakes. The Cologne Bight is in fact part of the Rhenish earthquake zone (see Figure 5.2) which ranges from Basel, in Switzerland, to the Benelux countries.

s0020 5.2.1 Heat Waves

p0030 Heat waves are extreme events in which hot temperature in summer months persist for a relatively long period of time. Impacts include human mortality and morbidity, costs for regional economies, and ecosystems degradation (Meehl and Tebaldi, 2004; Koppe et al., 2003). While there is no universal definition for heat waves, these are most commonly identified as events occurring when temperatures exceed both daytime high and night-time low thresholds (Vescovi et al., 2005) and this for a prolonged period of time. More specific definitions of heat waves require that thresholds are defined differently according to local conditions.

p0035 The Urban Heat Island (UHI) effect reflects the temperature difference between an urban area and its more rural surroundings and is mainly due to heat stored in buildings and in sealed roads (Gabriel and Endlicher, 2011). This effect, together with the higher concentration of air pollutants in cities (Wilhelmi and Hayden, 2010; Eliasson and Upmanis, 2000), aggravates the negative health related impacts of heat waves such as "skin eruptions, heat fatigue, heat cramps, heat syncope, heat exhaustion, and heat stroke" (Koppe et al., 2003). Causes of death or harm are linked to the age and fitness of elderly and to hazard factors such as the duration and intensity of the period of heat stress (Gabriel and Endlicher, 2011; Huynen et al., 2001).

p0040 According to Munich Re (2003), the European heat wave in 2003 caused over 20,000 deaths and an economic damage of 13,000 M US$. Other sources estimate the death toll to have reaches 70,000 excess deaths of which most were elderly (Robine et al., 2008; Brücker, 2005; Vescovi et al., 2005). The international disaster database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED) reported 9355 people killed and an economic damage of 1650 M US$ due to extreme temperatures in August 2003 in Germany only (CRED-EMDAT, 2013). The Health Department of Cologne estimated that approximately 100–120 people were killed due to the extreme temperatures in August 2003. Climate projections predict that heat waves will become more intense, longer lasting, and more frequent (IPCC, 2012; Luber and McGeehin, 2008; Meehl and Tebaldi, 2004). It is therefore necessary to monitor and adequately plan to prevent negative effects on the population also at this higher latitude. The City of Cologne learnt from the 2003 event and, considering the potential reoccurrence of heat waves in the future, developed guidelines for the population on how to cope with heat waves. Additionally, city authorities together with the German Meteorological Service, the State office for nature, environment and consumer protection, and the urban drainage department of Cologne finalized a project to derive concepts and strategies for climate change adaptation.

s0025 5.2.2 Floods

p0045 Cologne is considered to be the most flood prone area in Europe. Flow's peaks at the Cologne gauge station documented an upward trend during the last century with an average increase of about 25% (Pinter et al., 2006). One of the main drivers of this change, which leads to the magnification of flooding in the area, seems to be mainly anthropogenic or due to climate change. The 10 years average (2001–2010) mean tide level of the Rhine in Cologne is 3.21 m, while first flood protection measures start at a level of 4.50 m, and at a level of 8.30 m shipping traffic is interrupted (Urban drainage department City of Cologne, 2013). Table 5.1 shows all floods with more than 9.00 m level (Urban drainage department City of Cologne, 2013). Rhine floods in Cologne occur almost exclusively during winter months (Pinter et al., 2006) (see Table 5.1). Two floods which took place on the December 23rd, 1995 and on the January 21st, 1995 caused the highest damage in Cologne. The flood in 1993 caused four casualties and a damage of 65 M € whereas the economic losses in 1995 were about half of those in December 1993 (about 32.5. M €) as the population was better prepared, warnings were made in time and some measures were taken which largely reduced the damages and losses caused by the impacts of the flood (UNDINE, 2013).

t0010 **TABLE 5.1** **Floods Over 9 m Water Level in Cologne Since 1980**

Date	Water Level
05.01.2003	9.71 m
25.03.2001	9.38 m
02.11.1998	9.49 m
21.01.1995	10.69 m
23.12.1993	10.63 m
29.03.1988	9.95 m
10.02.1984	9.11 m
30.05.1983	9.96 m
14.04.1993	9.81 m
08.02.1980	9.31 m

p0050 After the 1993 and 1995 floods, an agenda was developed in the beginning of 1996: "The flood protection concept for Cologne". These emphasized the importance of retention measures and aimed at strengthening them through the reconstruction of embankments in the hinterland, reshaping brooks in a natural way, unsealing areas of increasing seepage, and structural flood mitigations like mobile walls, dikes, or flood detention constructions. Until 2008, altogether 400 M € were invested in order to protect Cologne up to a flood of 11.30 m and the zones most at risk are protected from floods up to 11.90 m, reducing in this way exposure.

s0030 5.2.3 Earthquakes

p0055 The region of Cologne is crossed by the lower Rhine Graben. In this area, earthquakes are frequent: between 1976 and 2002 the Bensberg station measured more than 1300 small quakes in the area. However, most of them are not felt by humans and do not cause damages. In the recent history, only the 1992 Roermond quake reminded inhabitants of the Cologne area that they live under seismic threat. In this event, 1 person died and 25 got injured, 7200 buildings were damaged, and the total amount of losses amounted to 75 M € (Pelzing, 2008).

p0060 Seismologists reckon that quakes with a magnitude of 6.7 happened in the past, and could still hit the region. This would cause severe damages, as a study about seismic risk mapping for Germany revealed (Tyagunov et al., 2006). In this study, an assessment of potential seismic damage was carried out and estimated losses to about 790 M € for Cologne only. A large part of the building stock in Cologne was erected in the 1950s, after the destructions of World War II. Recent constructions had to comply with current building codes (among which are also paraseismic rules), but the older stock is considered not to be resistant to earthquakes. In addition, the presence of industrial sites near Cologne could lead to severe, secondary, and indirect effects.

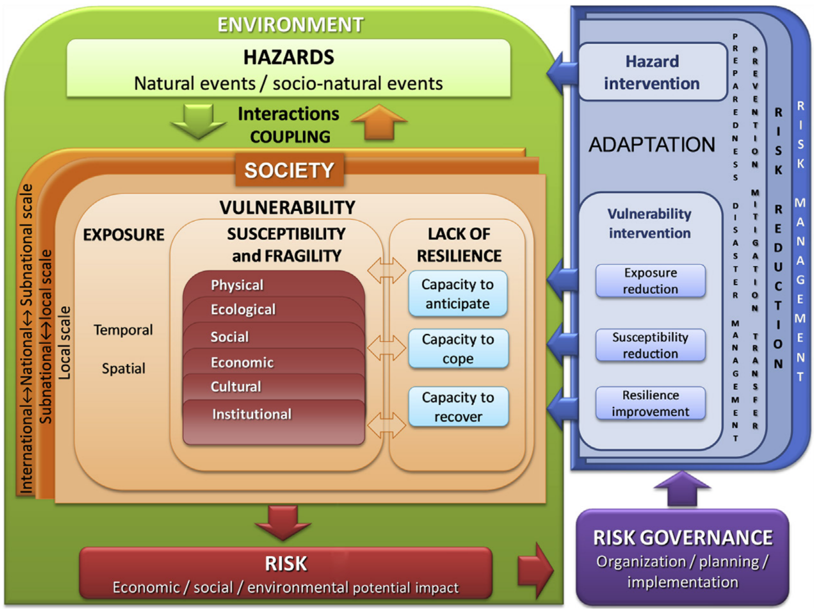
p0065 Earthquakes cannot be predicted. However a dense network of stations (operated by different institutions such as the University of Cologne and the geological Survey of North Rhine Westphalia) is constantly monitoring the region. The map presented in Figure 5.2 shows the different earthquake zones in NRW (Grünthal et al., 2006).

s0035 5.3 VULNERABILITY ASSESSMENT WITHIN COLOGNE: METHODS

p0070 The City of Cologne thus is prone to different hazards as described above. Overall the focus of the authorities has been on the features of the hazard more than on those of the social-ecological system that contributes to its vulnerability. Regarding floods, the municipality runs a flood competence centre which is a large network of stakeholders bringing science and practice together for a holistic flood protection which include risk assessments. Additionally the Urban drainage department of Cologne is also dealing with flood protection measures which again aim at lowering mainly exposure. We suggest an alternative and complementary method to spatially calculate risk to floods of the Cologne population based on a wide set of social indicators accompanied by some results and reflections on the ecological dimension of risk, mainly relevant at river basin scale but that should also be considered by local authorities.

p0075 Heat waves are recognized as an important topic within the health department of the municipality but no concrete risk and vulnerability assessment based on city district are available to date. We present here a detailed social vulnerability assessment of Cologne at the city quarter level. For an integrated vulnerability assessment of social and ecological dimensions at the district level please refer to Depietri et al. (2013). The vulnerability assessments that we present in this study provide relevant information for risk reduction since the focus is not solely on the natural hazard sphere but also encompasses the social conditions and coping capacities of the system.

p0080 Vulnerability assessment to hazards focuses in general on the likelihood of injury, loss, and disruption of livelihood caused by an extreme event and/or by the obstacles in recovering from the disturbance that a system can potentially experience (Wisner et al. 2004, p. 13; Wisner 2002, p. 12/7). The focus of a vulnerability assessment lies on the identification of the variables that determine the vulnerability of people, represented by major differences in their (potential and revealed) susceptibility, exposure, and resilience. The analysis presented in this chapter is based on the MOVE Generic Framework, which addresses vulnerability and disaster risk to natural hazards from an integrative, holistic, and multidimensional point of view (see Figure 5.3). In this context, vulnerability refers to the propensity of exposed elements such as physical or capital



f0020 **FIGURE 5.3** The MOVE Generic Framework used for vulnerability assessment (Birkmann et al., 2013).

assets, as well as human beings and their livelihoods, to experience harm and suffer damage and loss when impacted by single or compound hazard events and it is composed of key components such as exposure, susceptibility, and lack of resilience (or lack of societal response capacities) (Birkmann et al., 2013). Moreover, vulnerability is here described through different thematic dimensions such as physical, social, ecological, economic, cultural, and institutional.

p0085 The methods presented in this study assess different dimensions of vulnerability within Cologne related to three hazards. Precisely on the one hand: two quantitative assessment approaches focusing mainly on the social dimension of vulnerability toward floods and heat waves and on the other hand: one qualitative approach to the assessment of the environmental dimension of flood risk and one qualitative approach assessing the institutional dimension related to floods, heat waves, and earthquakes are presented. According to Birkmann et al. (2013), the social dimension of vulnerability is defined as the propensity for human well-being to be damaged by disruption of individual (mental and physical health) and collective (health, education services, etc.), social systems, and their characteristics (e.g., gender, marginalization of social groups). The environmental dimension refers to the potential for damage to all ecological and biophysical systems and their different functions and services (Birkmann et al., 2013). Finally the institutional dimension is defined as the potential for damage to governance systems, organizational form, and function as well as guiding formal/legal and informal/customary rules which might be forced to change due to the inadequacies they demonstrated while facing the hazard impacts.

p0090 The final assessment of vulnerability as described in the framework is translated into the following Eqn (5.1), both for the social dimension of vulnerability of the urban population to floods and heat waves:

$$V = E \times {}^{1}\!/_{2} \times (S + LoR) \quad (5.1)$$

where V is vulnerability, E exposure, S susceptibility, and LoR lack of resilience.

s0040 5.3.1 Assessment of Social Dimension of Vulnerability toward Heat Waves

p0095 The assessment of the social dimension of vulnerability toward heat waves comprises different datasets such as geo data and census data. Table 5.2 provides an overview of all data used, subdivided into the respective vulnerability key components.

t0015 **TABLE 5.2 Data Used for each Factor of Vulnerability to assess the Social Dimension toward Heat Waves**

Component of Vulnerability	Data Set	Data Source
Exposure	Thermal infrared satellite data of Cologne (June 30, 1993 at 9 p.m.)	Environmental department of Cologne
	Thermal infrared satellite data of Cologne (July 1, 1995 at 4 a.m.).	Environmental department of Cologne
	Number of inhabitants per city quarter	Statistical department of Cologne
	City districts (370 city quarters in Cologne)	Environmental department of Cologne
Susceptibility	Age groups (AG) 0–5 years + AG >65 years	Statistical department of Cologne
	Unemployment rate	Statistical department of Cologne
	Foreigners	Statistical department of Cologne
	Elderly households	Statistical department of Cologne
	City districts (370 city quarters in Cologne)	Environmental department of Cologne
Lack of resilience	Household members	Statistical department of Cologne
	City districts (370 city quarters in Cologne)	Environmental department of Cologne

p0100 The identification of adequate indicators and methods for each of the three factors of vulnerability is based on a literature review and on the results of expert workshops and stakeholder interviews. Several stakeholders and authorities of the City of Cologne were in fact contacted and interviewed in order to gather information and data, discuss the methodology and the outcomes of the study.

p0105 Following the MOVE approach exposure is defined as the number of people per administrative unit within the City of Cologne that can be potentially affected by extreme heat. The aggravating effect and differential exposure due to the UHI effect was integrated by using thermal remote sensing data which detect warm surfaces within the city. The thermal scans were conducted on June 30, 1993 at 9 p.m. for day temperatures and July 1, 1993 at 4 a.m. reflecting night temperatures. Exposure was then calculated using the number of inhabitants per city quarters multiplied by the normalized mean surface temperature per city quarter derived from thermal infrared satellite imagery. For the calculation of exposure in percentage the number of exposed population per city quarter was divided by the number of total population per city quarter.

p0110 Susceptibility indicators measure the predisposition of a society and ecosystems to suffer harm resulting from the levels of susceptibilities or fragilities of settlements and disadvantageous conditions and relative weaknesses related to ecological issues. For the case study of Cologne, the susceptibility indicators were extracted from census data. Based on literature review (e.g., Semenza et al. 1996; Brücker, 2005; Brown and Walker, 2008; Ebi, 2008; Fouillet et al., 2006; Klinenberg, 2001; Wilhelmi & Hayden, 2010), lessons learned from the 2003 heat event in Europe and stakeholders involvement age and health conditions, as well as socio-economic and socio-cultural factors are the main drivers that shape people's susceptibility. The following indicators for susceptibility were chosen for Cologne:

u0010 • Indicator 1 (Ind 1): age groups (AG) 0–5 years and AG >65 years (%)
u0015 • Indicator 2 (Ind 2): unemployment rate/city quarter (%), (Proxy: low income)
u0020 • Indicator 3 (Ind 3): foreigner/city quarter (%) (Proxy: problems in understanding of warning messages)
u0025 • Indicator 4 (Ind 4): elderly households/city quarter (%)

p0135 The indicators were weighted through expert judgments and aggregated based on Eqn (5.2):

$$S = (\text{Ind } 1 \times 0.6) + (\text{Ind } 2 \times 0.1) + (\text{Ind } 3 \times 0.1) + (\text{Ind } 4 \times 0.2) \quad (5.2)$$

p0140 Lack of resilience indicators measure the limitations in access to and mobilization of the resources of the social-ecological system, and the incapacity to respond by absorbing the impact. This factor of vulnerability includes the capacity to anticipate, cope, and recover in the short term. The selection of these types of indicators generally moves beyond quantitative aggregated demographic data and toward an understanding of knowledge, attitudes, and practices of individuals (Wilhelmi and Hayden, 2010). This type of information is not available in the form of statistics at the city quarter level and needs to be gathered through qualitative research. However, for this study, based on the understanding of safety nets in the form of social networks, the following assumption was made: the bigger the household (HH) is, the more HH-members are available, the more the elderly, invalids, and children living in the household can be assisted. This indicator is here used as a proxy for tight social networks measuring the capacity of the population to cope with extreme heat. For this indicator, data are available at the city quarter. Households with a single inhabitants of less than 30 years old were excluded in order to take into account only the older single households which are thought to be less able to cope with the hazard. The HH-sizes were then weighted based on experts judgment according to Eqn (5.2a) and (5.2b).

$$Coping\ Capacity = (1 * 5HH + 0,\ 8 * 4HH + 0,\ 6 * 3HH + 0,\ 4 * 2HH + 0,\ 2 * 1HH) / total\ number\ of\ HH \quad (5.2a)$$

$$Lack\ of\ Resilience\ (LoR) = 1 - Coping\ Capacity \quad (5.2b)$$

p0145 To aggregate the factors exposure, susceptibility, and lack of resilience into vulnerability, Eqn (5.1) was used. Thereby all factors are expressed in the range between 0 and 1, where 1 represents the highest negative value. For example a susceptibility value of 1 would mean that every HH within a city district is susceptible.

s0045 5.3.2 Assessment of Social Dimension of Vulnerability toward Floods

p0150 Information about the datasets used for the assessment of the social dimension of vulnerability toward floods are provided in Table 5.3.

p0155 The exposure indicator for floods was derived by calculating the number of people who are affected by an extreme flooding event classified by an HQ 100. For this, spatial data at the administrative units of Cologne, demographic data per administrative units, and the flooding hazard layer, which is a product of a hydrological model showing the inundated areas and inundation depth, within the City of Cologne, were collected. The flooding hazard layer was combined with the population data in order to calculate the potential number of exposed people to an extreme flooding event (see Figure 5.10).

p0160 More in detail susceptibility was derived from census data and the selection of the indicators is based on the results of previous studies (Fekete, 2010). Steinführer and Kuhlicke (2007) provides a table of indicators that shows characteristics of high propensity to suffer harm from floods e.g., elderly might suffer more physical and health impacts and are less capable of following emergency measures promptly and effectively (Thieken et al., 2007). Very young people need more time to evacuate (Birkmann et al., 2008) and lower income groups have a lower degree of insurance available and are, in this way more, vulnerable than others (Steinführer and Kuhlicke, 2007; Thieken et al., 2007). Additionally, education and household size were identified as relevant indicators since people with lower levels of education support less and are less capable of performing emergency measures effectively (Steinführer and Kuhlicke, 2007; Thieken et al., 2007).

t0020 **TABLE 5.3 Data Used for each Factor of Vulnerability to assess the Social Dimension toward Floods**

Component of Vulnerability	Data Set	Data Source
Exposure	HQ 100 flooding hazard layer	Environmental department of Cologne
	Number of inhabitants per city quarter	Statistical department of Cologne
	City districts (370 city quarters in Cologne)	Environmental department of Cologne
Susceptibility	HH-type 1: includes households with children less than 6 years	Statistical department of Cologne
	HH-type 2: includes household-members solely between 6 and 59 years	Statistical department of Cologne
	HH-type 3: includes people older than 60 years by a household size of minimum two persons	Statistical department of Cologne
	HH-type 4: includes single households older than 60 years	Statistical department of Cologne
	City districts (370 city quarters in Cologne)	Environmental department of Cologne
Lack of resilience	Occupancy per household	Statistical department of Cologne
	City districts (370 city quarters in Cologne)	Environmental department of Cologne

p0165 Focusing on emergency measures, such as the evacuation ability of exposed people, the following assumption was made: regarding susceptibility, different households were characterized by people who might be in need of external help in case of a flooding event (named evacuation ability). This information is of high relevance for civil protection, since they are in charge of organizing the evacuation. The Statistical department of the City of Cologne provided data calculated by means of the HH Gen (Household generation method) software, which categorized all households into 11 classes based on their size and age of inhabitants. These 11 classes were again classified into four classes in order to guarantee an area-wide applicability: (see Table 5.4): HH-type 1 includes households with children less than 6 years; HH-type 2 includes household-members solely between 6 and 59 years; HH-type 3 includes people older than 60 years by a household size of minimum two persons; and HH-type 4 includes single t0025 **TABLE 5.4** Evacuation Ability of Various HH-Types in Cologne Based on a Household Survey

	Question Within the Household Survey: "Would You Be Able to Evacuate Without External Help?"	
HH-Types	**Yes**	**No**
HH-type 1	91.7%	8.3%
HH-type 2	95.3%	4.7%
HH-type 3	88.2%	11.8%
HH-type 4	60.5%	39.5%

households older than 60 years. As a second step, we carried out a household survey were we asked a question related to the individual evacuation ability of each HH-type. The result of this survey is shown in Table 5.4.

p0170 Both information, the number of HH-types and the results of the question regarding evacuation ability, were used to calculate the indicator percentage of HH who are not able to evacuate without external help. This indicator reflects the susceptibility of the individual city districts toward a flooding event (see Eqn (5.3)).

$$S_{floods} = (number\ oHH - type\ 1 \times 0.083) + (number\ oHH - type\ 2 \times 0.047) + (number\ oHH - type\ 3 \times 0.118) + (number\ oHH - type\ 5 \times 0.395) \quad (5.3)$$

p0175 Characteristics which strengthen the resilience of people are, according to Steinführer and Kuhlicke (2007), Birkmann et al. (2008), and Thieken et al. (2007), higher income and higher education as well as bigger household sizes or experience with the hazard such as floods. The assumption that the degree of coping capacity of several households is dependent on their individual experience with flooding events has also been documented (Steinführer and Kuhlicke, 2007). Inhabitants who already experienced a flood know how to react before, during, and after it and have awareness of its negative consequences such as physical or mental problems which follow an event. The indicator on flood experience allows identifying which city quarters the households show low capacity to cope with flooding and thus need more awareness training. The information needed for the development of the indicator "flood experience" is first derived on the occupancy of the individual households (variable x, see Eqn (5.4)) and the degree of exposure at the place of residence. Then more information was obtained through the households survey in which the following question was asked: "How many households have already experienced a flood at their place of residence?" By using the binary answers (Yes, No) to the mentioned question as a dependent variable and the occupancy as independent variable a logistic regression model was set up in order to assess the percentage of households per city district with flooding experience as a measure of resilience. Following logistic regression model Eqn (5.4) was used.

$$P(Y=1) = \frac{e^z}{1+e^z} \textit{with } z = b_0 + b_1 x_1 \tag{5.4}$$

p0180 The lack of resilience is calculated by using one minus flooding experience (see Figure 5.12). To aggregate all factors to vulnerability Eqn (5.1) was used.

s0050 5.3.3 Assessment of Environmental Dimension of Vulnerability toward Floods

p0185 Due to the regional scale at which regulating ecosystem services for flood mitigation in Cologne are produced and to the numerous hard infrastructures distributed along the river Rhine, the assessment of the direct link between the provision of these services and the benefits the urban population derives for flood mitigation was not a straightforward task. A quantitative assessment was not deemed appropriate to calculate ecosystem services given the high surface of the river basin and the high human intervention in the river. A qualitative approach was then chosen to assess the level of awareness of the ecological dimension of risk to floods.

p0190 The perception of local authorities about the environmental dimension of vulnerability was investigated through a questionnaires and the results discussed with respect to other related studies. Stakeholders' interviews were carried out between December 2011 and January 2012. Interviewees were identified at the city level amongst those institutions in charge or contributing to the planning and management of ecosystems and those responsible or active in the sector of human health also at the city level. A list of 25 relevant institutions and organizations was drafted. The list was discussed internally, benefiting from our previous experience of working with disaster risk in Cologne. Some of the institutions contacted via mail and/or phone refused to participate as they did not consider their daily work to be strictly relevant for our study, but, nevertheless, some of them pointed out other local authorities that they thought would be more appropriate to be involved in our analysis. We finally ended up with a list of seven institutions willing to be interviewed which covered exactly the set of dimensions we considered in our study (see Table 5.5).

p0195 The interviews were based on a questionnaire composed of open questions divided into two sections: the first set focused on the perceptions of the interviewees with respect to the role of regional/river basin ecosystems to mitigate the impacts of floods in Cologne; while the second focused on past, witnessed, and potential impacts of floods on the local urban and peri-urban ecosystem and its services (e.g., water supply, recreational activities) and thus, indirectly on the urban population. Each interview lasted from 40 to 60 min, was recorded and then transcribed. The transcribed text was analyzed making use of the Atlas.ti (ATLAS.ti Scientific Software Development GmbH, Berlin) software, which t0030 **TABLE 5.5** List of the Stakeholders Interviewed

Interviewee	Male (M)/ Female (F)	Position	Type of Institution	Sector
1	M	Project manager	Municipal	Environment
2	M	Head of department	Municipal	Landscape and urban green areas
3	M	Head of department	Municipal	Public health
4	F	Head of department	Municipal	Urban planning
5	M	Head of department	Municipal	Water management
6	M	Professor	University Institute	Public health
7	M	Project manager	Local branch of a national NGO	Forest management

supports qualitative data analysis. The software facilitates the cross comparison of texts by coding the information and allows for the generation of knowledge avoiding the reduction of the complexity contained in the data collected.

s0055 5.3.4 Vulnerability Assessment of the Institutional Dimension with respect to Heat Waves, Floods, and Earthquakes

p0200 The institutional dimension refers to the organizational form and function as well as guiding legal and cultural rules. This assessment approach differs clearly from those described above, since the performance and internal processes of individual authorities within a city were analyzed and no differentiation into exposure, susceptibility, and lack of resilience is feasible.

p0205 For the assessment of the institutional dimension, stakeholders from following authorities were involved: Environmental department, Statistical department, City development department, Parks and open space department, the Flood protection center, and the Geological survey of NRW were interviewed in order to receive an understanding of how processes and structures are perceived within institutions with respect to heat waves, floods, and earthquakes.

p0210 The indicators chosen were semiquantitative: the information is clearly qualitative but is assessed on a five level scale. Following 15 indicators were used which cover several aspects of institutional vulnerability: (1) principles,

(2) aim, (3) trust, (4) internal accountability, (5) external accountability, (6) justification, (7) representation, (8) access to information, (9) tolerance toward the process, (10) dialogue, (11) financial resources, (12) staff resources, (13) role of experts, (14) coordination, (15) cooperation. These indicators were derived from past projects, in which they had been tested and validated. Each indicator was applied to the three hazards considered in this case study (i.e., earthquakes, floods, and heat waves).

p0215 The indicators were not weighed but all represented on a graph (see Figure 5.12 for the results of institutional dimension).

s0060 5.4 RESULTS

s0065 5.4.1 Results for the Social Dimension of Vulnerability toward Heat Waves

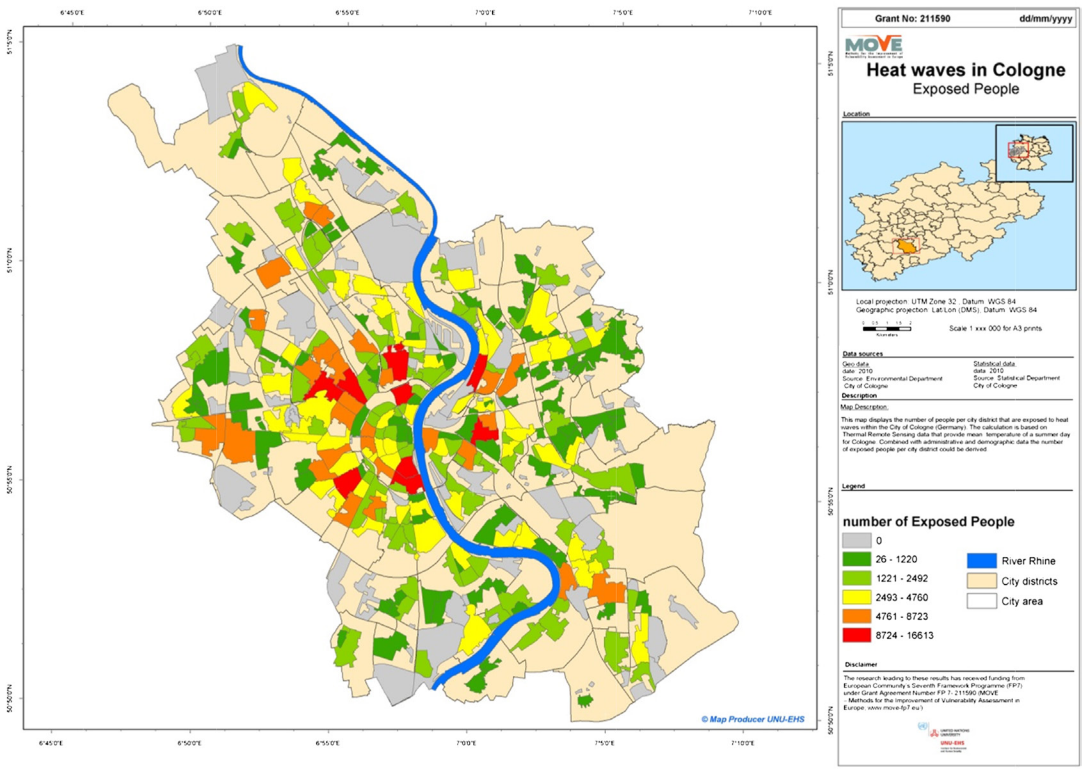
p0220 For the spatial analysis and mapping, the values of the calculated indices were separated into five classes using the quantile classification method, which is a tool of ArcGIS 9.3.

p0225 Figures 5.4–5.7 show the results for exposure, susceptibility, lack of resilience, and vulnerability of social dimension toward heat waves at city quarter level. Thus, Figure 5.4 shows the result for the exposure which was dependent on the surface properties and their heat retention capacity for each city quarter in combination with the respective population. Each city quarters could be identified with the highest and lowest number of exposed people. In general, a heterogeneous pattern of exposure was measured where the city quarter east of the river Rhine show a lower degree of exposed people than the quarters on the west side.

p0230 The result for the susceptibility to heat waves in the city of Cologne is presented in Figure 5.5. The four indicators used for its measurement are based on socio-economic information obtained from the Statistical department of the City of Cologne. It is shown that the city centre of Cologne and the two city quarters Villen Viertel and Andreas Viertel are situated in the lowest susceptibility class since single and younger households, such as of students, inhabit these quarters. It is worth noting that the more susceptible city quarters are located in the outskirts of Cologne.

p0235 The lack of resilience, or the lack of coping capacity, is shown in Figure 5.6. Since this indicator is focusing on household size, an inverse picture compared to the susceptibility map is noticeable. It can be seen that the city centre has a high lack of coping capacity since mainly single households are located in it whereas higher coping capacities can be found in the outskirts of Cologne.

p0240 According to Eqn (5.1) all components of vulnerability are aggregated in one vulnerability index. Figure 5.7 illustrates the different vulnerability patterns regarding heat waves in Cologne. The most vulnerable city quarters are located



f0025 **FIGURE 5.4** Exposure map of Cologne related to heat waves.

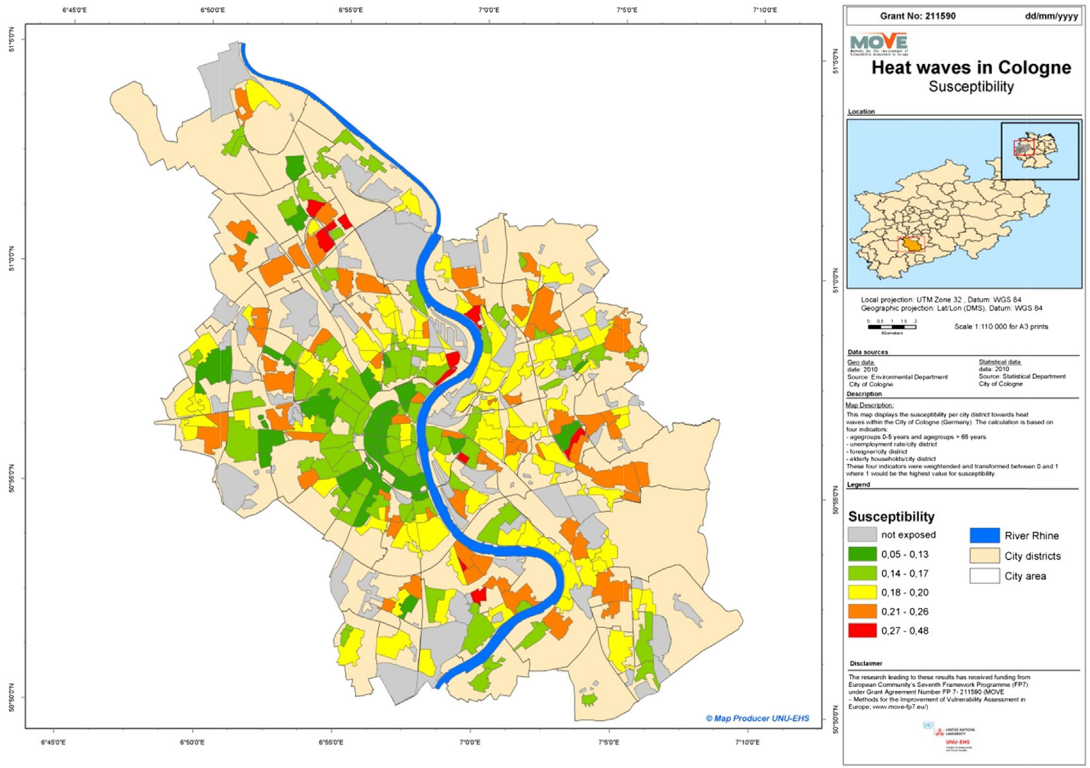


FIGURE 5.5 Susceptibility map of Cologne related to heat waves. f0030

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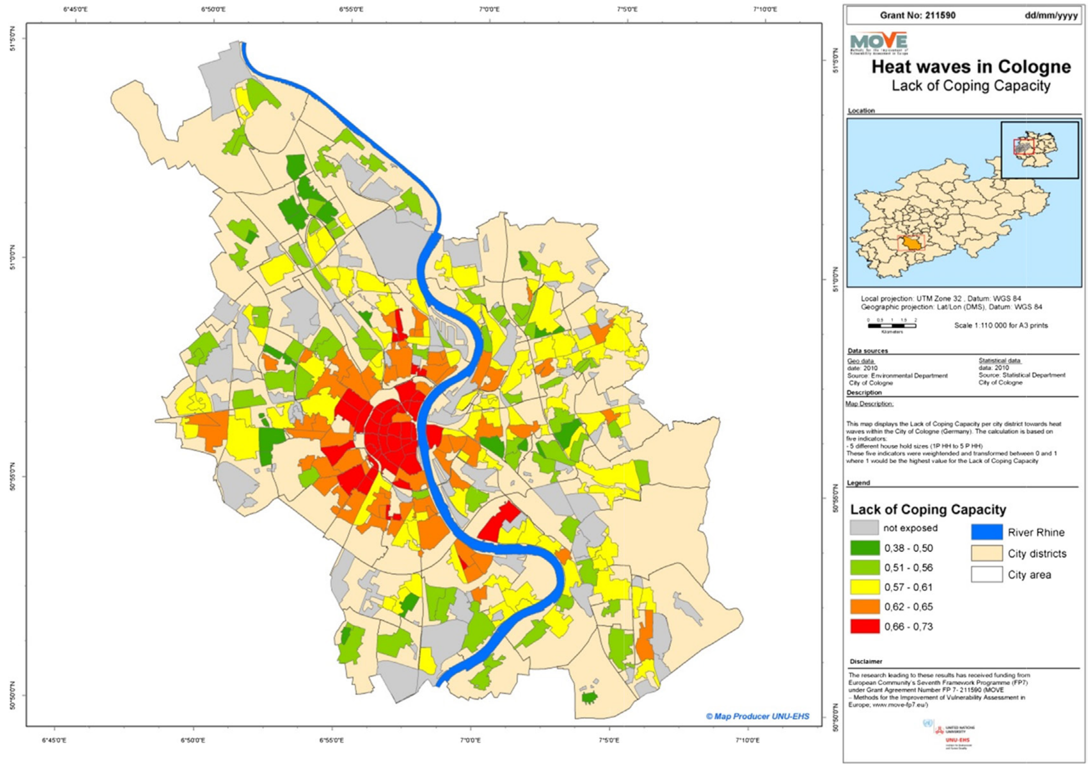


FIGURE 5.6 Lack of coping capacity map of Cologne related to heat waves.

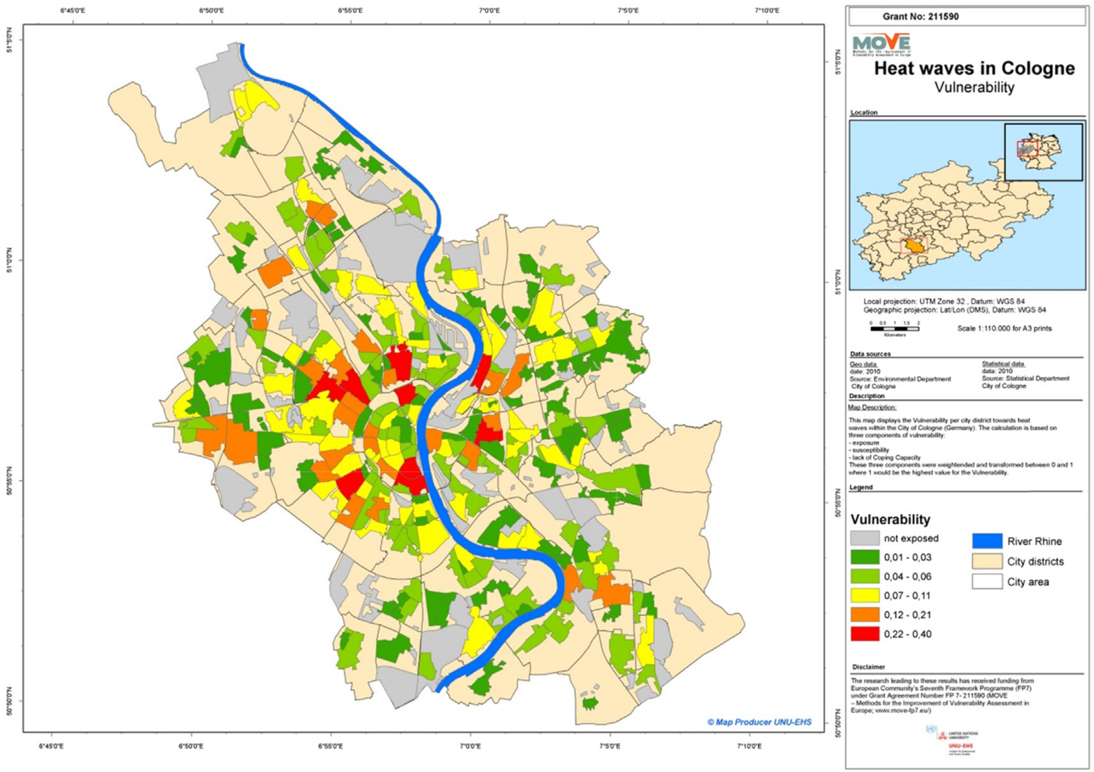


FIGURE 5.7 Vulnerability map of Cologne related to heat waves.

f0040

close to the city centre whereas the outskirts are in general less vulnerable. The western part of Cologne shows more vulnerable city quarters than the east of the Rhine.

s0070 5.4.2 Results for the Social Dimension of Vulnerability toward Floods

p0245 Figures 5.8–5.11 show the results for exposure, susceptibility, and lack of resilience and vulnerability of the social dimension of vulnerability toward floods.

p0250 Figure 5.8 shows the results for the flood (HQ-100) exposure in Cologne. Compared to the exposure to heat waves the calculation or detection of exposed areas and exposed people is more explicit since the hazard and its extent could be clearly identified based on the modeled hazard layer. Thus the most exposed people are within the city quarters that are located along the Rhine.

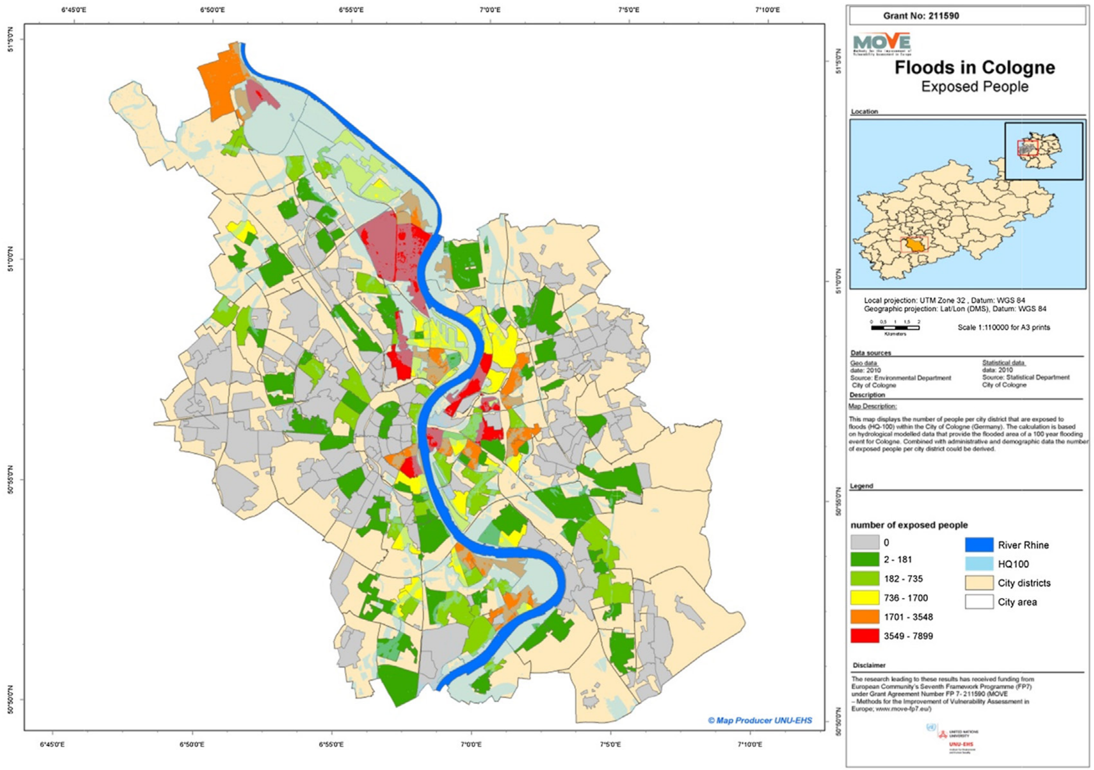
p0255 The susceptibility was calculated only for the exposed city quarters. The most susceptible city quarters result to be located east of the Rhine as well as in the North-Western part of Cologne. Less susceptible quarters could be identified around the city centre (Figure 5.9).

p0260 Figure 5.10 shows the results for the calculation of the lack of coping capacity toward floods in Cologne or inexperience with floods. The households with high experience are located in the south of Cologne (Rodenkrichen) and in the north of Cologne (Mülheim).

p0265 The overall vulnerability map with respect to floods is displayed in Figure 5.11. The hotspots of vulnerability are located along the river and in the northern part of the City. In the western part of Cologne low vulnerability values could be identified since these city quarters are less exposed, less susceptible and offer a higher degree of coping capacities as compared to those quarters located along the river Rhine.

s0075 5.4.3 Results for the Environmental Dimension of Vulnerability toward Floods

p0270 The results of the stakeholders' interviews regarding the ecological dimension of floods in Cologne are summarized in Table 5.6. Most of the respondents strongly agreed that the forest cover, the state of soils, and wetlands at the river basin scale have a positive effect on the reduction of the magnitude of floods in Cologne. Current upstream urbanization has therefore also an impact and increased flood risk between 1960 and 2010. It was mentioned that as agriculture rather decreased in the past decades, it is urban expansion the main driver of deforestation in the basin. To mitigate floods in Cologne the main strategy so far has been the creation of new retention areas, some of which are nearly to be constructed in Langel/Porz and Worringen. A retention area in Cologne is also constructed in Dungel, with 5 M cubic meters of volume for the retention of flooding waters. A project is just starting with a construction of a



f0045 **FIGURE 5.8** Exposure map of Cologne related to floods.

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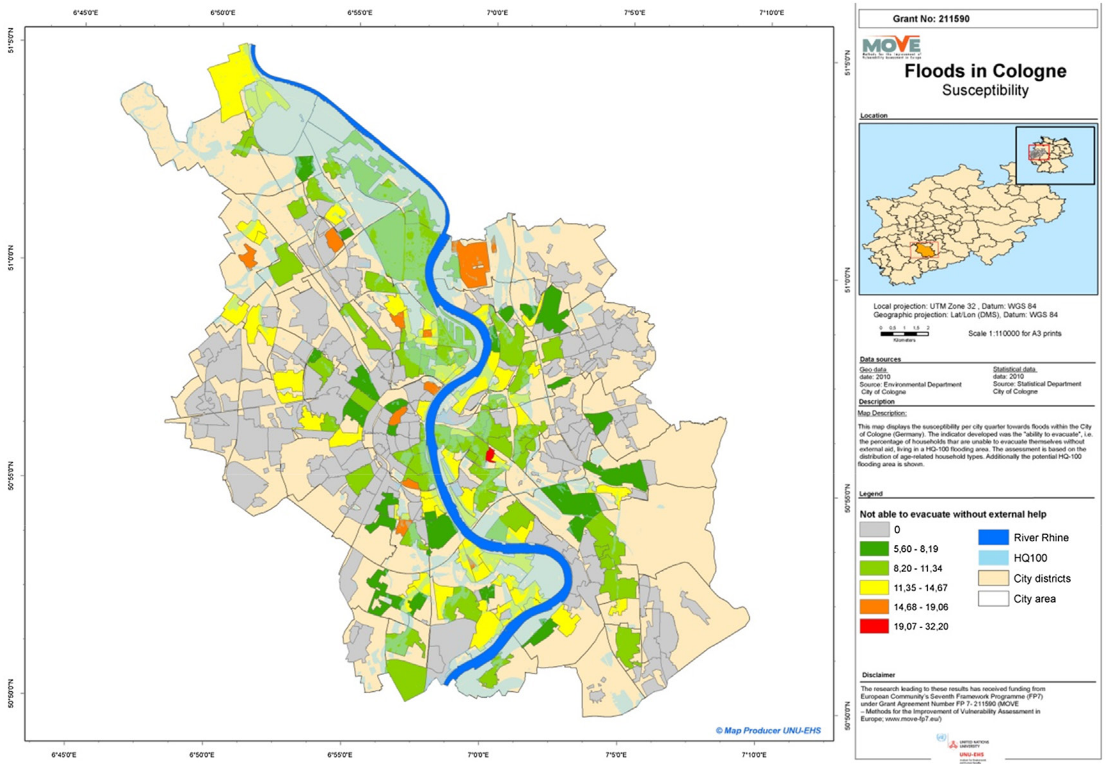

FIGURE 5.9 Susceptibility map for Cologne related to floods.

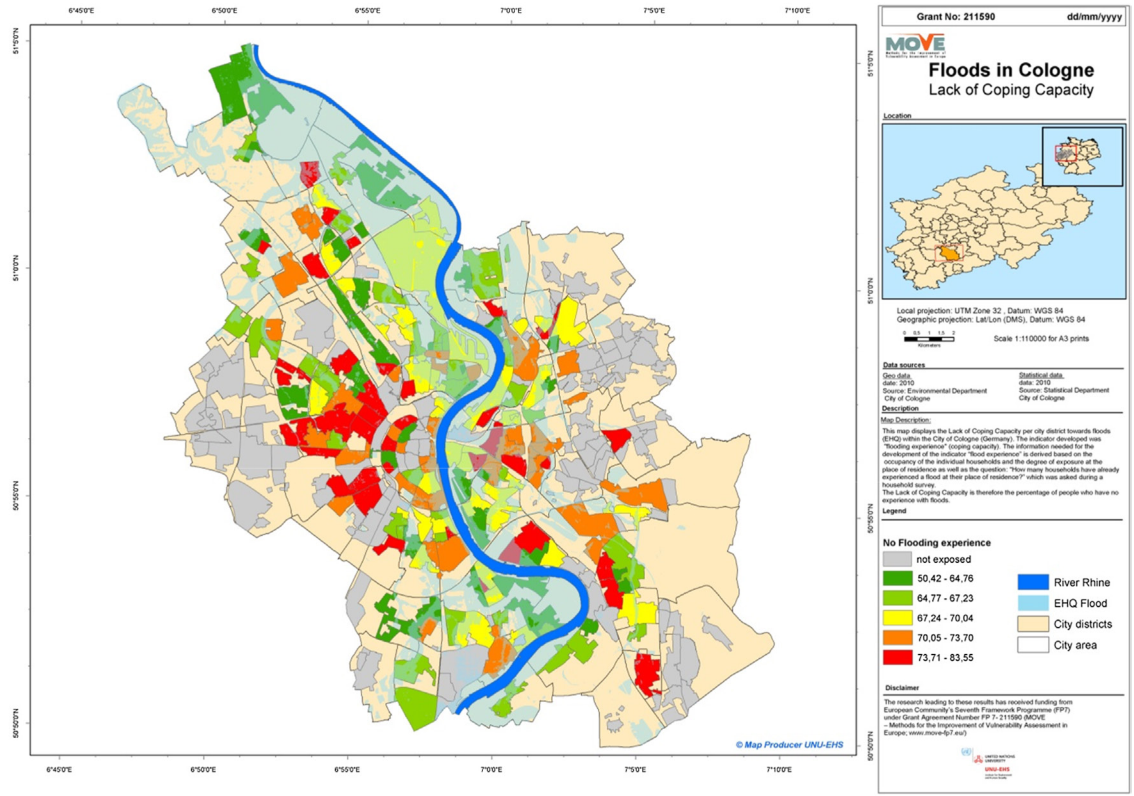

FIGURE 5.10 Lack of coping capacity map of Cologne to floods.

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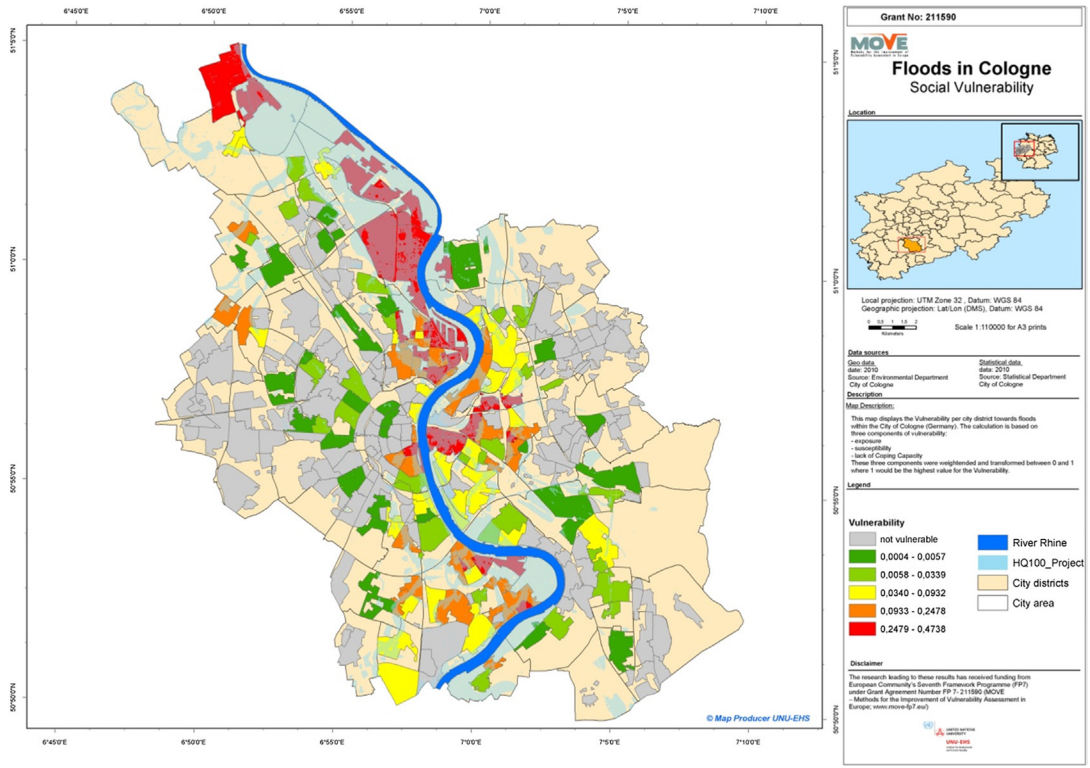

FIGURE 5.11 Vulnerability map of Cologne related to floods.

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t0035 **TABLE 5.6** Stakeholders' Perceptions on the Ecological Dimension of Floods in Cologne

Ecosystem	Ecosystem Service	Relevance (H = High, M = Medium, L = Low)	Benefit (River Basin Scale)	Impact (Local, Urban Scale)	Actions to Be Taken
Forests	Flood regulation	H	Moderate flood peak through better water infiltration, diminished runoff	Forested areas which are not adapted to persistent flooding, in case of an important flood, that take place each 100 or 200 years, can be damaged. Oaks would perish while alder and willow tree can resist to prolonged submergence. For long periods also poplar and street trees along the Rhine can be affected (especially for 5–6 weeks of submergence). However most of the vegetation does not get affected. Local soil sealing does not have an impact	Regulate urban expansion which is considered as the main driver of forest loss
	Recreation (city scale)			Recreational areas that might be flooded are Poller and Wiesen	
Soils	Flood regulation	H (at the river basin scale)	Water infiltration	Erosion and sedimentation	Plan to contain or reduce soil sealing
	Flash floods regulation	H (at the city scale)	Water infiltration The capacity of soils to retain water around Cologne is thought to be very high	Erosion and sedimentation in Cologne can happen but at insignificant rates and affects groundfloors and garages	Plan to contain or reduce soil sealing The type of soil should be used as an indicator of the retention capacity of the area rather than the type of land cover

Wetlands	Flood regulation	H	Water retention and release at slower rates	Wetlands and small water bodies can be affected in case of floods at the city scale	Preserve and restore wetlands upstream. The design of retention ponds should take into account the potential role of wetlands upstream. River embankments that disconnect the river from wetlands and flood plain should be avoided. See the International Commission for the Protection of the Rhine (ICPR) plan.
Freshwater	Water supply	L	Water supply	None	Pumps are immediately shut down in case of a flooding Monitor microbiological parameters
	Recreation	M	Recreational activities (e.g., fishing or swimming/bathing)	Water quality may deteriorate	Monitor microbiological parameters

Continued

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TABLE 5.6 Stakeholders' Perceptions on the Ecological Dimension of Floods in Cologne—cont'd

Ecosystem	Ecosystem Service	Relevance (H = High, M = Medium, L = Low)	Benefit (River Basin Scale)	Impact (Local, Urban Scale)	Actions to Be Taken
Urban	Shelter and recreational activities	M	Shelter and recreational activities	Mud and fungus can grow causing unhealthy indoor environments. Industrial sites along the river are mostly safe with respect to flood hazards. Of higher risk are households and industrial sites where the water table can dangerously rise Some recreational areas can get affected but this does not cause important damages because of the wide variety of recreational areas in Cologne	Early warnings
Agricultural land	Food	L	Food provision	In the south of Cologne some agricultural land might be flooded	(N.B. Most of the agricultural land is not situated close to the river)

volume of 30M cubic meters also upstream of Cologne. Most of the projects mentioned regard the construction of infrastructures to contain flood nearby the city. Finally, according to the respondents, floods at the city scale might gain in importance in the future. For this type of risk, the rate of soil sealing in Cologne becomes an important factor to consider.

p0275 The second part of the questionnaire focused on the impacts of floods on the urban and peri-urban ecosystem and their services (see also Table 5.6). Most of the respondents agreed that water supply sector is not affected by flooding and that there is sufficient groundwater which is hardly affected by the hazardous event. Artificial lakes around Cologne on the other hand might be affected or contaminated. The industrial areas around the city are considered to be very safe with respect to floods, and agricultural land is not situated close to the river. It is thought by the majority of the respondents that there is not a major risk of pollution (anthropogenic risk) in Cologne related to floods. Some respondents nevertheless underlined their concern for oil tanks around Cologne which might be damaged during an event. Sedimentation around Cologne is not considered as a major problem. Regarding impacts to the vegetation, only rare floods occurring every 100 or 200 years can have an impact on the vegetation and recreational activities when the forest can be affected being submerged for long periods.

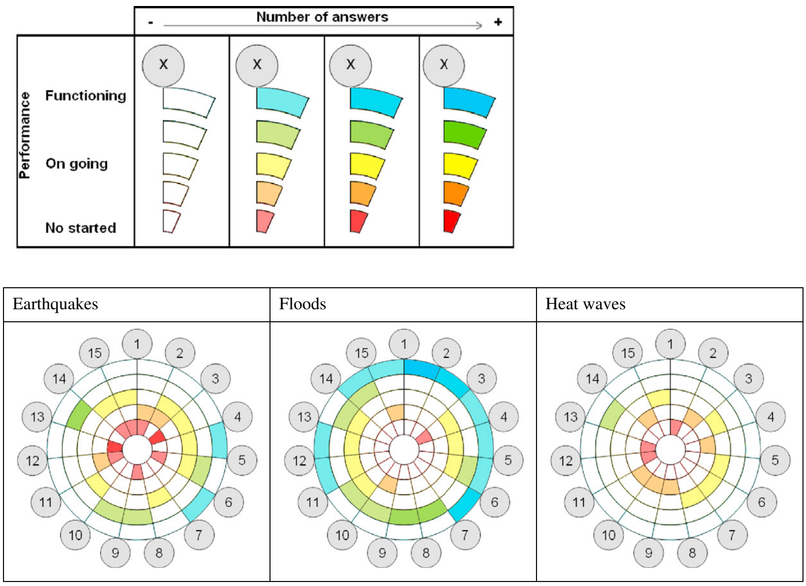
s0080 5.4.4 Results for the Institutional Dimension of Vulnerability toward Earthquakes, Floods, and Heat Waves

p0280 The answers of the stakeholders are represented in Figure 5.12.

p0285 The performance of risk governance processes is hazard dependent. It can be clearly seen that floods are already well addressed. The performances of the associated risk governance processes are seen to be good in most domains. Earthquakes, although authorities and stakeholders are aware of the risks, do not attract as much attention. If scientists and experts have a clear role, the lack of risk management policy appears as a major problem. Heat waves have a specific status in Cologne: attentions arouse only recently (after summer of 2003) and the willingness to address this issue was expressed immediately after. However, the risk management policies are still being defined and it is too soon to give an opinion on their performance. Uncertainties still have to be waived, and regular repetition of a similar study would be of interest to monitor the evolution.

s0085 5.5 DISCUSSION AND CONCLUSION

p0290 Different methods have been presented and applied to assess different dimensions of vulnerability of Cologne to the main three hazards that would affect the city. The results of vulnerability assessment for heat waves (Figure 5.7) and for floods (Figure 5.11), based both on Eqn (5.1), show that the exposure factor has a big influence on the overall vulnerability of the city. This is due to the fact that we multiply exposure with the weighted sum of susceptibility and lack of



1. Principles	6. Justification	11. Financial resources
2. Aim	7. Representation	12. Staff resources
3. Trust	8. Access to information	13. Role of experts
4. Internal accountability	9. Tolerance towards the process	14. Coordination
5. External accountability	10. Dialogue	15. Cooperation

f0065

FIGURE 5.12 Scheme of questions and results of the stakeholder discussion regarding institutional vulnerability.

resilience. Different weights for each factor of vulnerability could also be used based for instance on expert judgments or stakeholder opinions. The calculation of each of the different components of vulnerability however provided additional information on the reasons behind the distribution of vulnerability. Especially for heat waves for which susceptible groups appear to be more sparsely located around the city centre in areas which appear less exposed due partly to the minor UHI effect.

p0295 Indicators and indices, on the other hand, cannot fully meet the requirements of a theoretical concept. It has to be considered that the development of indices is a systematic and creative process in which representative data and variables is identified, gathered, obtained, or calculated and evaluated to solve certain problems. The advantage of an aggregated vulnerability index is the possibility of reducing a complex situation to one single value, which allows grasping the current situation at one glance. The individual factors and the aggregated vulnerability index which could be used for communication and can serve as first basis for decision-making. The validity of the indicators has been tested by external stakeholders.

p0300 Complementary information to the quantitative assessment of the social component of vulnerability to floods was derived through the perceptions of the relevant city level authorities on the environmental dimension. This moved the focus toward the more regional, river basin scale at which most of the responded identified important sources of provision of regulating services to mitigate flood risk in the city. Improving upstream ecosystem condition is then perceived as providing an effective strategy to reduce exposure to floods in Cologne. However, according to the literature wetland reclamation along the river might have some impacts on flood risk while land-use changes play a minor effect on large floods in large catchment areas such as the river Rhine (Disse and Engel, 2001; Hooijer et al., 2004; Pinter et al., 2006). A city regional approach as suggested in Depietri et al. (2014) might need to be strengthened in Cologne. Furthermore, according to the respondents, urban and peri-urban ecosystems and their services, on the other hand, would not suffer significant degradation or failure due to ordinary floods, lower than 100 HQ. Floods that affect Cologne take in fact place mainly in the winter time and when vegetation is dormant. Rhine summer floods on the other hand can affect vegetation in the basin (Vervuren et al., 2003) affecting recreational activities. As mentioned earlier, the assessment ecological dimension of vulnerability to heat waves was presented in Depietri et al. (2013). It resulted, at the contrary, that urban and peri-urban ecosystems play a central role in shaping the vulnerability of Cologne to heat waves and that improvements in their management could significantly lower the exposure as well as strengthen the resilience of the urban population.

p0305 Overall, it was shown that the MOVE theoretical framework can be applied to different hazards and to different dimensions (social, ecological, and institutional) and lead to policy relevant results. The presented methodological approach required data and resources which are currently used for different purposes by stakeholders in Cologne. The results are therefore also easily understandable and transferrable in the local decision making context. Stakeholder workshops, bilateral cooperation, and the results of the institutional assessment of vulnerability clearly showed that the perception and the relative importance of the three studied hazards are rather unbalanced for Cologne. In particular, the awareness of the city's population and local authorities with regard to heat waves and earthquakes needs to be strengthened.

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ALEXANDER: 05

Non-Print Items

Abstract

The MOVE framework was used in order to assess vulnerability toward heat waves, floods, and earthquakes in an urban area. It focused mainly on the social dimension of vulnerability for the smallest administrative unit within the City of Cologne (city quarters) with respect to heat waves and floods using specifically designed indicators. Reference is also made about the ecological dimension of flood risk of Cologne which is mainly relevant at the regional scale. Furthermore, the institutional vulnerability of different urban authorities dealing with risk reduction and risk governance is assessed with respect to the three hazards considered. The results derived from the spatial analysis of the social dimension of risk to heat waves and floods show different patterns of vulnerability mainly defined by the exposure and provide a first base of spatial information which could serve as a good communication tool of risk for several authorities in the Cologne Municipality. Ecosystems play a role at the river basin scale as risk in Cologne is related to land use and wetlands reclamation upstream but the environment and its services seem not to get much affected at the local, urban scale due to floods. Heat waves and earthquakes are less considered in risk governance processes compared to floods.

Keywords: Disaster risk reduction; GIS methods; Index building; MOVE framework; Urban areas; Vulnerability assessment.