Urban Regions:

Vulnerabilities, Vulnerability Assessments by Indicators and Adaptation Options for Climate Change Impacts

- Scoping Study -

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City of Meißen flooded by the River Elbe, 2002 (© Marc Zebisch)

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Context and aim of the scoping study

In April 2009, the European Commission published the White Paper “Adapting to climate change: Towards a European framework for action”. A key aim for the first phase of this framework is developing the general knowledge base in order to inform stakeholders on appropriate adaptation actions at suitable locations and scales. This includes enhancing the understanding of the territorial distribution of vulnerability to climate change in Europe (Harvey et al. 2009).

Vulnerability to climate change in its general meaning is a measure of possible future harm (Hinkel 2011) and a function of a range of biophysical and socio-economic components (O’Brien et al. 2004). Vulnerability assessment by indicators can support a number of different policy-relevant purposes (see Harvey et al. 2009, p. 33 for more details), such as:

- Raising awareness,
- Determining allocations of money or other forms of support,
- Monitoring progress of reducing vulnerability, or
- Measuring effectiveness of adaptation activities.

Vulnerability indicators can help European policy-makers to recognize more clearly the territorial distribution of vulnerability to climate change across the European Union. This information can help inform investment decisions under cohesion or structural policies. For example, climate change related vulnerability indicators are wanted for the regional development framework of the EU Territorial Agenda process to support territorial cohesion[1]. The Territorial Agenda aims to mobilise the potential of European regions and cities at utilizing territorial diversity for sustainable economic growth and employment through integrated spatial development.

At the European level, various organisations are already involved in the development of climate change related vulnerability indicators such as:

1. In the European Commission, DG REGIO led the Regions 2020 project, which included the development of a Climate Change Vulnerability Index. Its objective was to understand the regional distribution of vulnerability in order to guide the future strategy of DG REGIO to correct regional imbalance. Although the project aimed to investigate the possibilities of vulnerability indicators, it was not expected to make direct policy recommendations..
2. The Joint Reseach Center of the EU (JRC), is currently developing a European Database of Vulnerabilities for Urban Areas (EVDAB; http://moland.jrc.ec.europa.eu/evdab/evdab.htm). EVDAB aims to collect and integrate relevant datasets for the identification and the evaluation of key vulnerabilities of EU cities and their urban zones to weather driven hazards such as flooding, heat waves and droughts. Taking data from DG REGIO and Eurostat, the database gives outputs such as urban exposure to floods and wild fires. It is planned to use country level adaptation investment data from the DG REGIO cohesion fund report and to scale it down to city level as a measure of adaptive capacity.

[1] http://www.eu-territorial-agenda.eu/Pages/Default.aspx

3. The European Environment Agency (EEA) has initiated a project “Towards an Integrated Urban Monitoring in Europe (IUME)”. In this frame the EEA and other European partners review the European situation on available and needed urban information such as data, indicators, and assessment tools; it will propose further indicators to support better integrated urban assessments for different policy areas.

This study assesses the feasibility of developing climate change related vulnerability indicators for urban areas to support future EU spatial development policy by reviewing available literature and research activities. The aim of the project is to assess and test the potential for developing policy-relevant and scientifically-sound vulnerability indicators for EEA stakeholders (European Commission and European city networks) to indicate which cities and urban regions might be harmed by climate related threats.

Currently, a structured information dataset to understand the distribution of vulnerability to climate change impacts across the EU is lacking. This study was therefore commissioned to provide added value in terms of information overview and to:

- Collect and analyse the existing information on climate related vulnerabilities of European cities and urban regions (see chapter 3)
- Collect and analyse the approaches to assess climate related vulnerability by vulnerability indicators for European cities and urban regions, including an evaluation of the different approaches and an outlook to future activities (see chapter 4);
- Test, with a practical focus, existing vulnerability indicators (for specific climatic hazards and European cities), identify data needs and availability for applying vulnerability indicators (see chapter 5);
- Give an overview of existing adaptation options and activities in urban regions and cities in Europe (see chapter 6);
- Make recommendations for the development of a set of vulnerability indicators that could be used as starting point to compare EU-wide vulnerabilities in urban regions to support the EU spatial development policy (see chapter 1);
- Develop recommendations for a full report in 2011 about vulnerability indicators and adaptation options in urban region similar to the EEA 2008 report on impact indicators (see chapter 1).

Glossary

Term	Definition used in this study
Adaptation	Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc. (IPCC 2007).
Adaptive Capacity	The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007). In this project the adaptive capacity of a system is formed by the system's potentials to adjust to climate variations including the ability to learn from experience or information and hence to reduce its sensitivity (e.g. availability of air conditioning). However, components determining sensitivity and adaptive capacity are not easily separated, since future sensitivity depends on current adaptive capacities and measures.
Climate Change	Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC 2007).
(Climate Change) Impacts	The effects of climate change on natural and human systems (IPCC 2007). Climate Change impacts may be positive or negative (opportunities or threats), may be the result of extreme events or more gradual changes in climate variables and maybe experienced either directly or indirectly by the system of interest.
Climate variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the *climate* on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the *climate system* (*internal variability*), or to variations in natural or *anthropogenic external forcing* (*external variability*) (IPCC 2007).
Exposure	The nature and degree to which a system is exposed to significant climatic variations (IPCC 2001). In this project exposure is determined solemnly by the variations of climate (e.g. temperature during a heat wave) and the likelihood of its occurrence independent of characteristics of the affected system; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events.

Hazard	A threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area[2].
Potential Impact	The combination of exposure and sensitivity defines the degree of the potential impacts of climate change to a system. A combination of the potential impact and the adaptive capacities defines the vulnerability of a system.
Sensitivity	The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC 2007). In this project, the sensitivity of a system under observation is determined by its (structural) physical and socio-economic characteristics which are directly or indirectly influenced by climate variations and which are rather static and not easily changed (e.g. location, elevation, building structures, age structure of population).
Vulnerability	Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its *sensitivity*, and its adaptive capacity." (IPPC 2007). A useful shorthand definition is that vulnerability to climate change is a "measure of possible future harm" (Hinkel 2011). To fully define vulnerability it is good practice to specify: o the entity that is vulnerable, o the stimulus to which it is vulnerable, and o the preference criteria to evaluate the outcome of the interaction between the entity and the stimulus (Ionescu et al. 2009).

[2] http://glossary.eea.europa.eu/terminology/concept_html?term=hazard

1 Summary and recommendations for the future report

This chapter pulls together both the conceptual background to urban vulnerability to climate change (chapter 3), the data, approaches and indicators currently available (chapter 4) and the evaluation of specific approaches (chapter 5) as well as the overview about adaptation activities in European cities (chapter 6) to make recommendations for the EEA on taking this work further.

1.1 Summary of the report

There are a number of important activities required to prepare the ground for a more comprehensive study on vulnerability indicators for urban regions in Europe. This scoping study is part of a process (see Figure 1) towards a more comprehensive study to follow as outlined below.

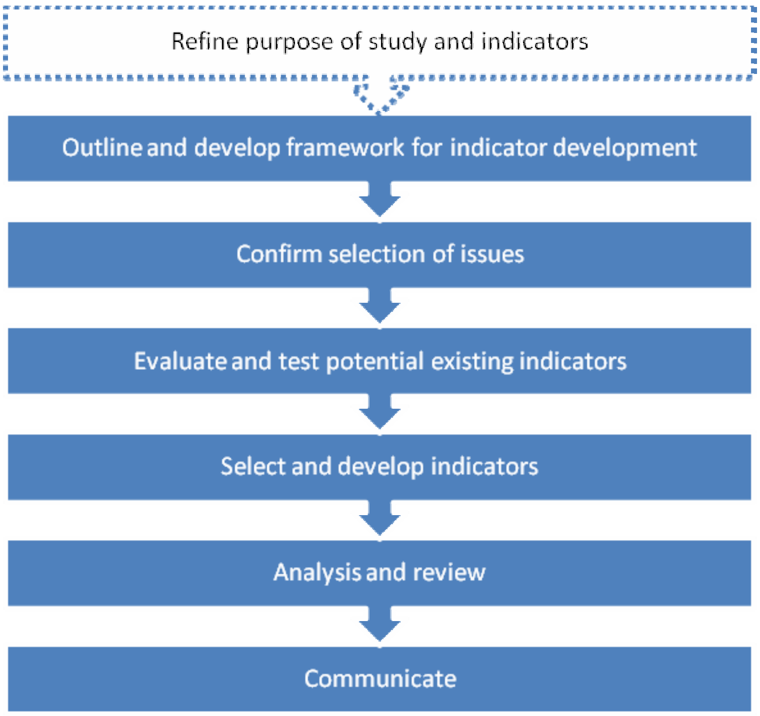

Figure 1. Recommended process to develop a comprehensive study.

Purpose of this scoping study

Currently, a structured information dataset to understand the distribution of vulnerability to climate change impacts across the EU is lacking. Therefore, this study assesses the feasibility of developing climate change related vulnerability indicators for urban areas to support future EU spatial development policy by reviewing available literature and research.

Framework for indicator development: Understanding of vulnerability

This report uses the vulnerability definition of the IPCC (2007) as starting point based on the elements exposure, sensitivity and adaptive capacity. This definition has limitations and is difficult to operationalise because the form of the function is not clear and the terms used are not accurately defined; also the concept of adaptive capacity has considerable overlap with the concept of sensitivity. The study uses an extended definition to allow a better assignment of different indicator components to the three elements of vulnerability.

Selection of issues: Main vulnerabilities of urban regions in Europe

Based on the work of Harvey et al. (2009), the study investigates 10 climate change issues for urban regions describing their main vulnerabilities in regard to climatic threats, the vulnerable systems and groups and the European macro-regions most affected. The causes and effects of most issues are well investigated in the literature although the details of the cause-effect chains for specific urban population groups or systems are often still unknown. There are also gaps regarding specific issues, because the climatic effect on urban systems has not been in focus of the existing investigations (e.g. wild fires, droughts, mass movements, and vector based diseases). The selection of the most important factors describing the sensitivity or adaptive capacity of a system is difficult because of conceptual and data constrains. Past or even future data on these factors is difficult to obtain or not available.

A further challenge is that much of our current and future information comes from quite specific studies of particular threats to particular groups at a particular time. There are challenges in trying to scale-up this information and the particular value of such material (e.g. the specific contextual components that influence vulnerability) are likely to be lost when applied with a coarser granularity across a wider area.

Evaluation of potential indicators: Existing vulnerability indicators for urban areas

There is no agreed method on how to quantify regions' or urban areas' vulnerability to climate change. The most common way to overcome this constraint and to make the concept of vulnerability operational is to use indicators. After having defined the purpose of a vulnerability assessment, indicating variables or indicator components need to be selected and aggregated for the creation of an indicator. The purpose of the assessment defines the temporal and spatial scale of the indicator components as well as the aggregation level.

Vulnerability indicators including components of exposure, sensitivity and adaptive capacity for urban areas have been identified mainly for heat waves and fluvial floods. There are also some vulnerability indicators available for wild fires, water scarcity, urban drainage flood and sea level rise. A lot of the existing indicators miss either exposure or adaptive capacity components. Overall, the indicators and approaches found and evaluated by this study tackle (and partly solve) the climatic threats and issues individually: The selection of the components is based on literature review but mainly data driven, leading to a wide range of components for indicators with a similar purpose. The aggregation methods vary from simple summation to complex statistical methods and to sophisticated multi criteria analysis. There is no evaluation or validation of the proposed indicators. The main shortcomings of the existing indicators are the missing theoretical background and transparency of their development: No convincing framework or methodology to select the components and aggregate them into an indicator could be identified.

The Preston et al. (2008) work on vulnerability indicators for the Sydney region could be identified as an example of good practice. However, it attempts to tackle a large number of critical issues at the same time, and it still faces similar problems in terms of conceptual gaps, knowledge gaps and problems with projecting into the future (particularly future adaptive capacity) that were identified as constraining the development of vulnerability to climate change indicators for European urban areas.

Further development of indicators: Information available in future

The general gaps relevant for developing climate change vulnerability indicators concern conceptual gaps, methodological questions, data concerns, and application gaps. At present, many ongoing initiatives and projects help 'plug' some of the more general knowledge gaps and help improve the existing threat specific vulnerability indicators. Within the scoping study, over 80 projects were identified with a potential to be relevant for the future study on urban vulnerability indicators. The majority of projects focus on conceptual and methodological issues and therefore are mainly appropriate to address those particular types of gaps. Some projects are key for future work as the expected outputs are directly relevant for the development of vulnerability indicators (e.g. EVDAB, ARCADIA, KIBEX, ECOCITIES, GRaBS, SCORCHIO). Some projects (e.g. CLIMSAVE, MEDIATION, MOVE, ENSURE, CLISP, ESPON – Climate Change) aim at improving the general methodology of selecting and aggregating vulnerability components.

There is a continuing challenge in drawing together the breadth and depth of relevant material at the European level, and there is a danger that indicators can become solely supply driven – in other words developed in a particular form because of the constraints of available data.

Analysis and review: Testing existing indicators

The application of vulnerability indicators at city level reveals a number of critical issues: indicators developed in one European country or region or at a particular scale are not or hardly transferable to other countries, regions or to other scale levels because of (1) data availability and data comparability, with data acquisition and data user rights as additional hurdles to take, and (2) availability of the information about the details of selection and aggregation methods.

Additional information: Projects on adaptation options of cities

A lot of projects concerned with adaptation to climate change have started in the past few years and are still running. Some of these connect adaptation with climate protection research (e.g. ASSCUE, ERKLIM), others focus on the impacts of specific threats such as floods (e.g. RISKMAP, FloodResilienCity), water scarcity (e.g. AlpWaterScarce, DMCSEE), sea level rise (e.g. MARE, COASTANCE) or heat (e.g. KLIMES). Impacts in specific European regions are addressed e.g. by CIRCE for the Mediterranean region, RESPONSES for coastal regions, or AdaptAlp for the Alpine region. Some projects investigate the adaption process as a whole to support adaptation policy (e.g. ADAM, CLISP) others are more concerned with the development or implementation of adaption options (e.g. BaltCICA, ESPACE). Only few projects are really focusing on adaptation options of cities and urban regions (e.g. CAT-MED, KLIMES).

This is expected to be enhanced in the forthcoming future, as the request for feasible adaptation options on city level increases. Already now "early adapters" emerge, which are European cities that address the challenges of climate change in more or less comprehensive adaptation approaches. Adaptation strategies are increasingly developed, for example in Birmingham and London (UK), Copenhagen (Denmark), Helsinki (Finland) or Bremen and Dresden (Germany). But also without such declared strategies, different measures like green and blue urban planning (as in Berlin, Rotterdam, Nijmengen and many more) and flood-preventive activities such as flexible barriers (Prague, Cologne) or retention areas (Pilsen, Katowice, Lyon) are becoming increasingly en vogue.

1.2 Strategic recommendations for the future process

As discussed in the report, there is a need to be specific about purpose when developing indicators because this will have a bearing on the appropriate method for developing indicators, the nature, type and quality of data used and ultimately the means of presenting the indicators to the target audience. As a reference for possible purpose of the full study, we can draw on the objectives of the EEA 2008 study. The stated objectives were to:

1. Present past and projected climate change and its impacts through easily understandable, scientifically sound and policy-relevant indicators;
2. Identify the sectors and regions most vulnerable to climate change with a high need for adaptation;
3. Increase awareness of the need for global, EU and national action on both mitigation (to achieve the EU global temperature target) and adaptation;
4. Highlight the need to enhance monitoring, data collection and dissemination, and reduce uncertainties in climate and impact modelling

We recommend that once the EEA has had the opportunity to consider this scoping study a roundtable or expert meeting is held to re-visit and clarify the purpose and objectives of the full study and the vulnerability indicators needed for that. This would need to include the EEA, experts from the European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation, other invited experts and representatives from the European Commission including DG CLIMA and DG REGIO. This meeting should also start the process of further developing or agreeing the framework to be used for indicator development which is presented in the following.

This scoping study provides a useful conceptual framework as a starting point but its utility will need to be re-visited in light of further reflection on purpose and on the outcomes of running projects. Examples of projects and methodologies developed outside a European context (see section 4.3 and 4.4) provide a useful means of benchmarking this scoping study and the framework suggested within.

The majority of work for the full report will then be to confirm the subjects of importance, which we described as climatic issues (Where, what and who – table 6, section 3.3) and then develop the indicators with time built into the process for further evaluation and review.

1.3 Recommendations on decreasing the knowledge gap for the development of vulnerability indicators

When describing the purpose of the vulnerability assessment it will be necessary to be specific about the dimensions of vulnerability at state (Füssel and Klein 2006, Ionescu et al. 2009) from the beginning on:

1. Definition of the system in question, e.g. spatial extension, economic system, specific population group;
2. Kind of climatic threat investigated, e.g. sea level rise, heat wave;
3. Potential damage or harm to the investigated system, e.g. economic loss, human health, human live;
4. Temporal scale of the harm expected, e.g. current vulnerability or future vulnerability.

In this scoping paper we collected and analysed considerable information and knowledge about existing vulnerability assessments by indicators and the dimensions of vulnerability.

By using the “issues concept” (Harvey et al. 2009) we were able to give an overview about the dimensions of vulnerability of urban regions (see chapter 3 and annex 7.1) connected to various climatic threats. Based on the literature review, we provide an overview about the current knowledge on which urban systems and urban population groups are vulnerable to which threat and how. However, for the impacts of the specific threat there is much more literature available and will be available next year which will need to be reviewed. Thus, **we recommend asking external experts to extend this overview for specific threats and develop the tables on the relationships between climatic threats and vulnerable groups and systems (see section 3.2) further.**

The project team and external experts found it challenging to use the IPCC vulnerability concept with its three elements and follow the structure of exposure, sensitivity and adaptive capacity. **We recommend that relevant experts are consulted to propose single components of vulnerability for each specific threat** (e.g. age structure) stating why it is important and in which way this component (or a combination of components) will influence the urban region (and more specific which system, which group by which damage). This justification should be considered an important element of the final report and will encourage transparency, credibility and pragmatism. The selected experts should also indicate the data availability in relation to the spatial and temporal scale. As starting point, the experts can use the descriptions of vulnerability and the components of the existing indicators (see annex 7.1). Some components will be important for different threats (since the same populations groups or systems will be affected). After the collection of information, a table can be created and structured by one central contact point into the three elements of vulnerability. It should also be used to define which kind of damage (damage to human health, economic loss, and ecosystem service damage) should be in focus for each climatic threat. The table can be used in an expert and stakeholder review to select the most important components to measure exposure, sensitivity or adaptive capacity (e.g. Werg et al. 2010).

We recommend focusing primarily on harm to vulnerable populations when doing a vulnerability assessment as this would simplify the selection of vulnerability indicator components (see section 1.4). The study of Werg et al. (2010) can be used as a starting point: they analysed the literature for heat, flood and storm and created a list of indicators to identify vulnerable groups. For each indicator, they described (1) why the particular indicator helps identifying vulnerable population groups, i.e. an assumption of the general effect on vulnerability, (2) why the indicator was included in the expert survey, i.e. studies that show correlation of the indicator with vulnerability, and gave (3) application example, i.e. a study that applied the indicator when mapping vulnerability for a certain area.

We found it rather difficult or impossible to differentiate current and future vulnerability because of the missing data for projections of sensitivity and adaptive capacity elements. For many socio-economic components only past data from the last census (which might be 10 or 20 year old) is available. Another aspect is that future vulnerability depends on past actions, acclimatisation and experiences. Thus, most existing indicators are measuring current or past vulnerability. Therefore, **we recommend searching for socio-ecological models for generating scenarios of future societal developments.** Until these are available, it will be necessary to concentrating on current (+/-10 years) vulnerability and to be clear that – in most cases - the future aspects relate only to climatic projections and maybe (if available) to population dynamics.

Since adaptive capacity is difficult to define and to measure, we collected information on adaption options and activities of urban regions as a possible measure of their adaptive capacity (see chapter 6 and annex 7.3). If experience and/or research would have proven that the damage of some threats could be reduced by some measures effectively and efficiently and cities have the potential to implement these measures, then their adaptive capacity in regard to this threat can be assumed to be low. However, the information on adaption activities of cities is spare and the effectiveness of the options is difficult to judge (see annex 7. 5 and 7.6). To achieve some further insights into the adaptive capacity of cities, **we recommend creating a table on adaption options (see annex 7.6) and asking cities to fill in whether they plan or implement these measures and how they evaluate them**. Alternatively, the approach of Werg et al. (2010) can be followed further, who selected threat specific indicators for sensitivity and adaptive capacity from literature and asked experts for their evaluation.

1.4 Recommendations on developing a set of vulnerability indicators

An important challenge in the development of vulnerability indicators is the need to balance pragmatism with ambition. There is clearly a requirement and need to develop robust, credible and salient methods for measuring vulnerability to climate change across Europe to inform different stages of the policy cycle. This is clearly expressed in the EU's White Paper (EC 2009b). However, it is equally clear that there are important practical constraints on what can be achieved in the short-term. Therefore it is worth seeing the planned report in the longer term and thinking at this stage how to balance the development of an initial set of indicators against longer term ambitions to update and develop the indicator set. Of course this will depend on the purpose for which the indicators are developed.

In this report, we could give an overview about the general challenges of selecting and aggregating vulnerability indicators (see section 4.1). We do not have a simple solution for these problems. However, when evaluating the existing indicators (see section 4.2) and existing frameworks (see section 4.3) we draw the following conclusions:

1. It is necessary to set up a conceptual framework or model which is flexible and transparent enough to be transferable to different threats.
2. The purpose of the assessment and also the used terms such as vulnerability, exposure, sensitivity, adaptive capacity, etc. needs to be defined as specific as possible.
3. The outcome of the exercise needs to be agreed, whether impact indicators, potential impact indicators (as in our terminology a combination of exposure and sensitivity components) or/and vulnerability indicators (as a combination of all three elements) shall be derived and mapped.
4. The selection procedure needs to be structured along the conceptual framework. The result is as easier to analyse as less components have been used. Selection should be based on scientific knowledge and discussed with experts and stakeholders.
5. The aggregation methodology should be as simple as possible to achieve transparent results which can easily be understood and analysed. Weights should be based on expert opinions or scientific knowledge.
6. The purpose of the assessment should determine the level of aggregation: one vulnerability value does not give much information on the causes of vulnerability. Therefore, it should be accompanied with information on exposure, sensitivity and adaptive capacity.
7. Interpretation and communication, including mapping, of the results is an important part of the assessment and should be done with great caution.

Thus, our recommendations for the future development of a consistent set of vulnerability indicators for urban regions in Europe are:

1. Define the purpose of these indicators. The purpose of the indicators defines the spatial and temporal scale, which indicator components and what level of aggregation is chosen. City managers interested in management planning will need a finer scale and less aggregated data to know where the vulnerable groups or systems are in particular (and why they are vulnerable) than European policy makers interested in comparing cities adaptation needs. It needs also to be defined whether the vulnerability of a city in general or the vulnerability of different urban population groups shall be measured (and whether the sum of them can be expected to be equal to the vulnerability of a city).

2. Use the IPCC vulnerability concept with its three elements as starting point, but differentiate further into spatial, bio-physical and social sensitivity. Define the single terms of the vulnerability concept adapted to the purpose of your assessment. It might be useful to use a similar definition than we have done, but be aware of the problems related to the differentiation between adaptive capacity and sensitivity. A way of differentiation could be to define variables which describe a (current) potential to undertake adaptation options that decrease the vulnerability to future hazards (in the spatial and temporal scale of the assessment) as adaptive capacity components, because adaptive capacity provides mainly information regarding the future vulnerability of a system. Thus, variables can be assigned as sensitive components which describe rather static aspects and aspects not modifiable by adaptation options.

3. The differentiation between spatial (e.g. topography), bio-physical (e.g. land-use in general) and social (e.g. population density) sensitivity components allows a stepwise combination (see Figure 2) of
   a. exposure with spatial sensitivity to indicate primarily WHERE the potential impacts will be (i.e. the areas most likely to be affected by climate change);
   b. the primary information (WHERE) with the bio-physical information to indicate WHAT is sensitive and could be affected (i.e. which land use or infrastructure);
   c. the primary information (WHERE) with the social information to indicate WHO is sensitive and could affected (i.e. which populations or which populations group);
   d. the WHAT information with appropriate adaptive capacity information;
   e. the WHO information with appropriate adaptive capacity information.

   Not for all threats all combinations are equal important. For some threats (e.g. heat) the "What (is sensitive)" information is of little interest, except it influences the "Who (is sensitive)" information. However, the links between the WHO and the WHAT are not yet integrated in any indicator, thus the vulnerability of people and infrastructures (or land use) should be dealt as two separate strands with two different metrics according to the different damage types.

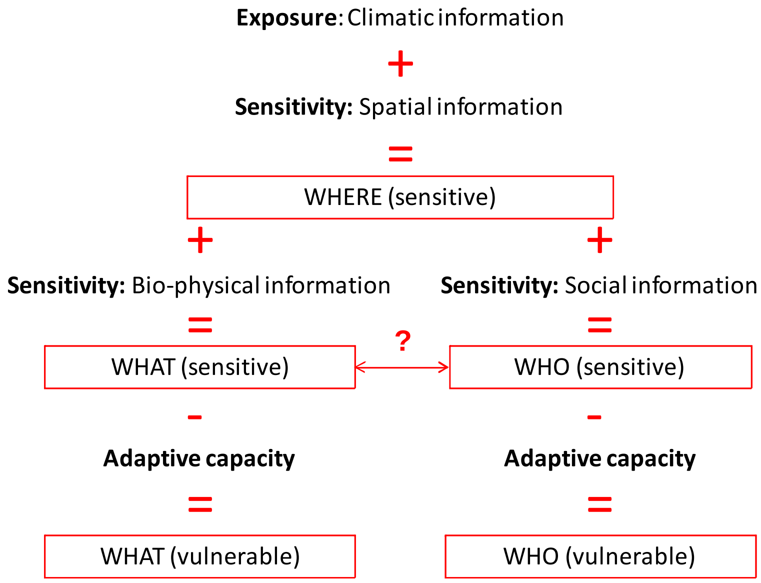

Figure 2. Flow chart for combining different aspects of vulnerability.

4. Start to integrate generic components for each vulnerability element and integrate stepwise more specific data based on the information provided in chapter 3 and annex 7.1 and an expert and stakeholder process (see section 1.3), for example heat related threats (see Table 1). More data do not necessarily contain more information but decrease the transparency of the result:

Table 1. Examples for indicator components of a vulnerability indicator to heat waves.

	Exposure: Climatic information	**Sensitivity:** Spatial information	Bio-physical information	Social information
generic	• Max. summer temperature	• Urban areas	• Land use (residential areas)	• Population density
specific	• Heat days • Tropical nights	• Impervious area	• Location of hot-spots (hospitals, old-age home, etc.) • Condition and age of dwellings	• Population above 65 yrs (and living alone) • Population with renal sickness • Population working outside
Adaptive Capacity:				
generic			• Blue and green areas	• GDP • Access to information via internet
specific				• Household income • Access to air conditioning • Installation of cooling centers

5. Regional vulnerability indicators should generally be normalized by population or area so that a region is not considered more vulnerable than another just because it is more populous or bigger (EEA 2010a). Use a simple and transparent aggregation method. There are no agreed rules or metrics for aggregation of variables or indicators existing. The aggregation of individual values into composite values of rather abstract meaning will always be subjective and disputable. Therefore we suggest avoiding complex aggregation methods that aggravate the interpretation of final results and apply simple, transparent and easily reducible methods. Do not aggregate all components together but do it stepwise and separated for the elements of vulnerability creating intermediate levels of aggregation that can later be communicated together with the final results. This increases the transparency of the procedure and decreases the risk to be biased by for example difference in the number of variables per component. When generating classes and aggregating variables use simple normalization and ranking procedures. For example, Preston et al. (2008) sums all variables per element separately and then rescores the sums to a scale from 1 to 9 based upon quintiles. The values of the three element layers are then summed up and rescored again to a 1-9 scale. Weights should only be used when based on expert opinion or scientific results (for further recommendation see section 5.4).

6. Use data at the spatial and temporal scale appropriate to the purpose of your assessment. Thus, it might not be appropriate to use the same thresholds across Europe, e.g. it is necessary to be spatial specific under which conditions heat related health damages might occur. Thus, concentrate on macro-regions with similar bio-geographic conditions and experiences when doing comparative vulnerability assessments.

7. Evaluate and communicate the results of vulnerability assessments with particular caution and consideration of their strengths and limitations. Discuss the results with stakeholders. Usually the outcomes of vulnerability assessments cover only partly the information required for decision making aiming at reducing the adverse impacts of climate change. Communicate not only the final results but all intermediate aggregation steps. Be particularly cautious with the selection of class borderlines and the choice of colors for mapping final vulnerability results since these choices might influence the outcome much more severely than any other pre-procedural step.

A way to simplify a vulnerability assessment would be to define explicit that the assessment is only concerned about the vulnerability of people and the direct damage potential to human health (and not on economic or ecologic damages). Thus, the size of the urban vulnerable population to specific threats (in regard to health damages or economic losses) can be used as a measure of the overall vulnerability of a city. Then, the whole assessment could concentrate on investigations defining who is vulnerable (and for most of the climatic issues in this report there are some publications about the vulnerable groups, see section 3.2, Table 5 as well as Werg et al. 2010). For a simple description of sensitivity then only those components need to be integrate, which describe the size and likely location of the vulnerable groups during the climatic threats.

For a pragmatic step forward in the development of vulnerability indicators, it might be appropriate to concentrate primarily on exposure and sensitivity, and thus on maps of potential impacts, since for these elements variables are most often investigated and quantified. However, adaptive capacity can influence the future vulnerability considerably. In the absence of threat specific information on adaptive capacity very generic information (such as GDP, education level, employment ratio) might be used as first approximation although the literature does not show a direct relation between such generic information and the vulnerability of urban population groups (Werg et al. 2010).

1.5 Recommendations for threat specific vulnerability indicators

This scoping study provides a useful starting point for the development of a more comprehensive report on the vulnerability of European cities to climate change (an indicator based assessment). This section provides pragmatic recommendations for the development of the full report by summarising the evaluation of the indicators identified by the scoping study as candidates for further development.

Table 2. Existing indicators, potential projects and next steps for climatic issues.

Climatic issues relevant to cities	How good are existing indicators and will ongoing projects or initiatives help with conceptual gaps, data gaps and other relevant gaps for this climatic issue?	What can be done in the near term and how this will help the process of indicator development? What are the first steps in making progress on indicators for this climate threat/issue?
Higher temperatures, heat wave and health	All the indicators are quite strong on the *exposure* element which is primarily a particular type of weather over a particular time frame (although	For pan-European applications then a more refined version of indictor of Harvey et al. (2009) would provide a measure of vulnerability of European urban areas to heat

Climatic issues relevant to cities	How good are existing indicators and will ongoing projects or initiatives help with conceptual gaps, data gaps and other relevant gaps for this climatic issue?	What can be done in the near term and how this will help the process of indicator development? What are the first steps in making progress on indicators for this climate threat/issue?
problems	definitions of heat wave will vary across Europe). There is also good data and some consensus (judging by data type utilised) on *sensitivity* in that particular groups are perceived to be more at risk. However, all indicators seem to struggle to pull these points together with any notion of adaptive capacity. Key on-going projects are ARCADIA, CLIMSAVE, SCORCHIO, KIBEX, MOVE, CLISP, EVDAB, ESPON climate Change and ECOCITIES.	waves if the data could be processed to the appropriate spatial scale. For more localised applications, then the detailed work undertaken for Manchester and Toronto warrant further evaluation and validation. The kind of information we would eventually expect to see from an indicator on this issue would be a measure of changing exposure (extreme temperature events) and changing sensitivity (social, economic and environmental changes – ageing population, increasing urban population, changing urban morphology etc.).
Decreased precipitation, water scarcity and drought	Although widely recognised in the literature as a potential risk from climate change, particularly for Southern European Cities, there has been little work in indicator development for the issue of decreased precipitation and drought. Partly this is a result of the difficulties of relating meteorological concepts and definitions to impacts. Only few projects related to vulnerability assessment are concerned with water scarcity: namely CLIMSAVE, SCORCHIO, MOVE, ESPON Climate Change, and CLISP.	The potential for developing the identified two indicators for a European scale and the possibility of further scaling at the city level needs to be evaluated based on existing data sources. A further option is to investigate more carefully current measures of water scarcity that may or may not take explicit consideration of climate change.
Wildfires	Only an Australian indicator could be identified during this review. Also in the on-going projects wild fire related vulnerabilities are of little concern, except in EVDAB, MOVE, and CLISP.	The identified indicator needs to be assessed and transferred to European Urban regions. Next steps would be to ask National Focal Points on Climate change and EIONET members if wildfires are currently a major issue for cities in EEA member countries, and to collate information on any on-going local research into the topic, specifically any addressing methodological, data and application gaps.
Heavy precipitation and fluvial floods	Current indicators concentrate mainly on either social components to identify vulnerable groups or geographical components to identify vulnerable buildings structures. There is considerable information available on exposure and	There is a considerable scope for further development at the European level and the need to agree the focus of such an indicator and draw on existing European-wide datasets. As starting point at the European level, the indicator of Harvey et al. (2009) and

Climatic issues relevant to cities	How good are existing indicators and will ongoing projects or initiatives help with conceptual gaps, data gaps and other relevant gaps for this climatic issue?	What can be done in the near term and how this will help the process of indicator development? What are the first steps in making progress on indicators for this climate threat/issue?
	sensitivity elements and a wide number of ongoing / planned initiatives that will further contribute information to this area. Relevant projects include: ARCADIA, INDIKATOREN, KIBEX, CLIMSAVE, MOVE, CLISP, ECOCITIES, EVDAB, ESPON climate Change	for more localised applications the work of Fekete (2009) and Meyer et al. (2009) or Kubai et al. (2009) can be used.
Intensive precipitation and urban drainage	Only an Australian indicator could be identified during this review. Key on-going projects to keep aware of are PREPARED, ClimateCost, MOVE, ARCADIA, and CLIMSAVE as they plan on covering more than one of the knowledge, methodological, data and application gaps identified for this issue.	The identified indicator needs to be assessed and transferred to European Urban regions. Next steps would be to make regular contact with the relevant research teams for intensive precipitation and urban drainage (via the lead partner for CLIMSAVE Oxford University and SEI Stockholm for ClimateCost) for these projects and to review the outputs for relevance to European cities and indicator development once published.
Sea level rise and storm surge-driven flooding	Considerable work has been done in this area. However, the proposed indicators concentrate mainly on geomorphological and biophysical characteristics. Only few indicators consider socio-economic parameters, mainly coastal population density. An interesting approach is used by Kleinosky et al. (2006) to calculate physical and social vulnerability independent, using different measures for current and future social vulnerability. Important project in this field are CLIMSAVE, ESPON Climate Change, and MEDIATION.	The indicators of Kleinowski et al. (2006) and Preston et al. (2009) can be used as starting points to develop existing indicators further and to identify an appropriate method to scale up the regional assessments and transfer the existing methods to different coastal types.
Saltwater intrusion into aquifers	Only in ESPON (Climate Change) these threats are investigated.	Next steps as follow on work in this area would be to ask National Focal Points on Climate change and EIONET members if saltwater intrusion is currently a major issue for cities in EEA member countries, and to collate information on any on-going local research into the topic.
Mass movements and erosion	The ACQWA, MOVE, and CLISP projects are set to address knowledge gaps for vulnerability to mass movements and	Next steps would be to make regular contact with the relevant research teams for mass movements for this project and to review the

Climatic issues relevant to cities	How good are existing indicators and will ongoing projects or initiatives help with conceptual gaps, data gaps and other relevant gaps for this climatic issue?	What can be done in the near term and how this will help the process of indicator development? What are the first steps in making progress on indicators for this climate threat/issue?
	erosion. There are alternative approaches developed in the disaster risk literature not accessed during this scoping study.	outputs for relevance to European cities and indicator development once published. Another next step would be to ask National Focal Points on Climate change and EIONET members if climate change linked mass movements and erosion are currently a major issue for cities in EEA member countries, and to collate information on any on-going local research into the topic, specifically any addressing methodological, data and application gaps.
Wind storms	It is expected that ASTRA, KLARA-Net Phase II and ESPON Hazards will address knowledge gaps in the area of wind storms and climate change	Next steps as follow on work in this area would be to ask National Focal Points on Climate change and EIONET members if wind storms are currently a major issue for cities in EEA member countries, and to collate information on any on-going local research into the topic.
Vector-borne diseases	It is expected that KLARA-NET phase II will address knowledge gaps in the area of vector-borne diseases and climate change.	Next steps would be to make regular contact with the relevant research teams for vector-borne diseases for these projects and to review the outputs once published. And to ask National Focal Points on Climate change and EIONET members if vector-borne diseases are currently a major issue for cities in EEA member countries, and to collate information on any on-going local research into the topic, specifically any addressing methodological, data and application gaps.

Most importantly, before any further resources are used on the investigation of these issues, it is advisable to consider which of the identified climatic issued are important enough to be developed further. A more comprehensive gap analysis and scoping exercise may reveal ongoing projects or initiatives within Europe that haven't been captured by this review. In the short-term there are a number of ongoing initiatives (see chapters 4.3, 4.4 and annex 7.2) that will help – but any outputs may not meet the requirements of the full report. The EEA should consider how comprehensive the initial set of indicators need to be and this will then need to be balanced with issues of quality.

1.6 Recommendations on the future report

This project has identified a number of possible *inputs* for the full study and it is expected that the *outputs* of the process will be a report, similar in type to the indicator-based assessment of climate change impacts (EEA 2008). When the purpose of the future report will be to raise awareness, it is useful to clarify whose awareness is to be raised and for what: A report on the vulnerability of European cities to climate change will raise awareness about vulnerability to climate change in a general sense and may become a useful benchmark and reference source for policy making at the European scale. However, a pan-European report may not provide added value to local city-based decision makers who may disagree with potentially contentious results or require much more specific information for implementation. How far it will be necessary to include methodological considerations in the future report, cannot be decided yet.

Dependent on the purpose of the report, the EEA needs to define at the beginning of the report whether it will consider impact, sensitivity, potential impact (in our terminology a combination of exposure and sensitivity components) or/and vulnerability indicators (as a combination of all three vulnerability elements). One approach can be to show for one climatic issue the whole series of impact, sensitivity, and potential impact, adaptive capacity and vulnerability maps based on the application of one vulnerability indicator. Another approach is to show different vulnerability maps based on different vulnerability indicators (e.g. see chapter 5). However, **we recommend that maps for the three elements of vulnerability are shown to enable a transparent interpretation of the results and indicate the reasons for the vulnerability of different cities or regions**. The differentiation into spatial, bio-physical and social sensitivity allows showing which areas as well as what and who might be affected by future potential climatic threats.

Out of practical reasons and data availability **we recommend to show different maps for only a few specific climatic threats.** None of the climatic threats identified in these study are specific for urban areas. Some might even have a more damaging effect on rural areas. When the urban regions and cities as well as vulnerability shall stay in focus of the future report, **we recommend concentrating on vulnerability to climatic threats investigated specially for urban areas such as heat and flood for which different indicators are available**.

In the report, **we do not recommend concentrating on cities alone but use information on wider (urban, suburban and surrounding rural) areas**, because cities depend on their lifelines (such as energy and water supply) meaning that cities are dependent on their surroundings. Alternatively, the dependencies of urban areas could be integrated as sensitivity factors in the vulnerability assessments. To be able to show information spatially differentiated, **we recommend to use raster data instead of vector data** (additional benefit: the delineation of the cities is less problematic and by using finer grids and more detailed data the same method can be used for finer scales).

A possible approach might be to differentiate city types, similar to coastal types, to derive and compare the vulnerability of these city types (e.g. the vulnerability of loosely build cities to a specific threat in comparison to densely build cities). However, we found it more precise to focus on the vulnerability of urban population groups directly, since the characteristics of a city (e.g. share of impermeable area, building density, population density, distribution of blue and green areas, building materials) as well as the condition of its infrastructures influence the population. Also, a European wide classification of city types is not available. Therefore, **we recommend integrating quantifiable**

city characteristics in the vulnerability assessment as sensitivity and adaptive capacity components where possible.

We emphasize the danger of combining vulnerability to different threats into one indicator since the kind of damage due to these threats might be very different, unless a common metric can be used. We also see a danger of comparing the impacts of a single threat over a wide regions such as the whole of Europe, since the vulnerability of the macro-regions is due to different preconditions, experiences and acclimatization which are not reflected in the indicator: e.g. people in the Mediterranean are much more used to heat than people in the Nordic countries.

2 Introduction

2.1 Importance of urban regions in Europe

Urban areas provide the engines of global economy, and are often responsible for the bulk of national output, innovation and employment. Due to the concentration of population and economic activities, urban areas are also responsible for the consumption of the majority of the world's energy and other resources (Corfee-Morlot et al. 2009). From almost 75% today, around 80 % of European people will be living in urban areas by 2020, mainly due to migration from rural to urban areas. Additionally, increasingly urban areas will experience cross-border immigration also triggered by the effects of climate change (EEA 2009a, EC 2008). Levels of urbanisation vary widely among Europe's regions), and tend to be highest in northern countries (see Table 3). Urban growth is disproportionately occurring in the hinterlands of existing large cities and in the medium-sized and smaller cities (UNCHS 2005).

Table 3. Projection of the level of urbanisation in Europe in 2050 (UN 2007).

Level of Urbanisation	2010 Urban area (%)	2050 Urban area (%)
Europe	72.6	83.8
Eastern Europe	68.8	80
Northern Europe	84.4	90.7
Southern Europe	67.5	81.2
Western Europe	77	86.5

In contrast to rural areas, urban areas can be defined according to different criteria, such as administrative entities (e.g. boundaries), morphological characteristics (e.g. specific land uses), or functional features (e.g. population density or thresholds, travel patterns). Due to inertia in the re-definition of administrative areas, the functional urban area typically extends well beyond the administrative and morphological boundaries of a town or city (EEA 2009a).

A city is a relatively large and permanent urban settlement. Many cities have a particular administrative, legal, or historical status based on local law. Cities generally have advanced systems for sanitation, utilities, land usage, housing, and transportation. The concentration of development greatly facilitates interaction between people and businesses, benefiting both parties in the process[3].

2.2 Impacts of climate change on urban regions

Climate change will affect urban areas directly in worsen existing urban problems, such as low air quality and poor water supply. Potential impacts of climate change on urban areas include (Dawson et al. 2009, EEA 2008):

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[3] http://en.wikipedia.org/wiki/City

- Sea level rise and storm surge flooding,
- Fluvial flooding,
- Urban drainage flooding,
- Building and infrastructure subsidence and landslides,
- Wind storm,
- Water scarcity , drought and implications for water resources both in terms of quality (and concomitant implications for health and aquatic ecosystems) and availability for human consumption, industry and neighbouring agricultural areas,
- Heat and health (changing profile of heat vs. cold related deaths),
- Air quality and health,
- Resources and amenity (including agriculture, fisheries, waste management, ecology, wildlife, biodiversity and fires), and,
- Diseases (changing profile of vector and water-borne diseases).

In summary, climate change is likely to affect human health, either directly from the physiological effects of heat and cold, or indirectly, e.g. by increased transmission of food- or vector-borne pathogens or in case of flooding. In the past, heat waves have been the main cause of weather-related health damages and deaths in Europe (such as in the US, see NWS 2008) with approximately 76.000 fatalities for the last 10 years (compared to 2 fatalities due to droughts, 482 because of storms, 1024 because of floods)[4]. There is evidence that human population will partly acclimatise to future temperatures, supported by adaptation options, such as for example heat alert systems and adapted urban building design. In future, sea level rise and associated changes in the frequency and/or intensity of extreme weather events, such as storm surges, will increasingly threaten many coastal cities such as London, Rotterdam, Barcelona, Athena affecting a few million of people (EC 2009a, Behrens et al. 2010).

For the built environment, extreme events are the main potential impacts of climate change: floods and storms, and to a lesser extent cold- and heat-waves or droughts (Hunt and Watkiss 2007). In relation to these effects, there is likely to be a strong regional pattern, exacerbated by the geographical conditions of a city as well as its physical conditions, urban design and management. Research, undertaken particularly by the insurance sector, quantifies the past and potential future costs of climate change for the built environment[5]. It identifies storms as being currently the most expensive weather events in the developed world (Hunt and Watkiss 2007). Other research identified pluvial floods as causes of the bulk of socio-economic damages (Pitt 2008), which are likely to also become a major problem in many European urban areas especially those experiencing an important

[4] CRED - WHO collaborating Centre for Research on the Epidemiology of Disasters, Catholique University of Louvain. Analyses by Philippe Hoyois and Debarati Guha-Sapir on EMDAT online disaster database, http://www.emdat.be

[5] Hunt & Watkiss 2007: ABI (2005) estimated that by the 2080s, there would be a 5% increase in wind-related insured losses from extreme European storms. Swiss Re recently estimated that in Europe the costs of a 100-year storm event could double by the 2080s with climate change (USD50/EUR40 billion in the future compared with USD25/EUR20 billion today). Other estimates indicate that the cumulative contribution of changing climate risk and socio-economic development are likely to double worldwide economic losses due to natural disasters every ten years.

expansion of the built environment (EEA 2010a). It is noted, however, that the observed upward trend in flood damage can also be attributed to socio-economic components, such as the increase in population and wealth in flood-prone areas, to changes in the terrestrial system, such as urbanisation, deforestation and loss of natural floodplain storage, as well as to changes in climate (Hunt and Watkiss 2007).

It is projected that especially heat waves and intense precipitation events, especially in winter, will become more frequent throughout Europe. Some regions are expected to be especially exposed to the following threats (e.g. EEA 2008, EEA 2010a, Behrens et al. 2010):

- In southern Europe: more heat waves, droughts and water scarcity,
- In central and eastern Europe: more droughts, heat waves and river floods,
- In northern Europe: more damages by winter storms and floods,
- In mountain areas: more natural hazards, including floods and rock falls,
- In coastal areas: sea level rise and increased frequency of storm surges

2.3 Reasons for the vulnerability of urban regions and cities to climate change

The physical and socio-economic characteristics of a city influences its sensitivity against climate change impacts and can therefore lessen or worsen the risks. For example, urban density and vegetation cover have strong influences on the hydrological cycle and temperatures in a city and the degree of soil sealing determines the potential for water infiltration after heavy precipitation. Others features include (CAP 2007):

- Asphalt, concrete and other hard surfaces in the city absorb radiation from the sun, causing the urban heat island effect, which exacerbates heat waves and puts pressure on electricity generation and distribution systems.
- Hard surfaces also prevent absorption of rainfall, creating runoff that carries pollution to lakes and streams and can overwhelm storm water systems, leading to sewer backups and flooding of public and private property during heavy precipitation events.
- Combined sewers that carry both storm water and sewage are common in many city centres. Protracted or intense precipitation leads to overflows in these sewer systems, washing untreated pollutants into local water bodies.
- The concentration of people in urban centres puts pressure on vegetation and green spaces that could reduce heat, storm water runoff, pollution and social pressures.
- Far-flung supply lines combined with just-in-time shipping practices can result in shortages of needed goods when transportation is disrupted by extreme weather.
- Centralized power sources, longer distribution lines, and an increasingly interconnected grid increases vulnerability to blackouts when electricity demands are high – during heat waves, for example – and when storms occur. The impact of blackouts has also grown as homes and businesses have become more dependent on electronic control and communication systems.
- The concentration of people in large cities creates a large demand for water and can strain local water supplies, making them more susceptible to water shortages in drought conditions.
- Urban sprawl and competition for building sites has led to construction in locations such as floodplains or steep slopes that are vulnerable to extreme weather.

- Low-income city dwellers in substandard and poorly insulated buildings that increase the risks from heat waves and other extreme weather. Homeless people have almost no protection from these events.

Cities are also very dependent on their “lifelines” – infrastructure systems to transport people and goods, communications systems, water and energy distribution, sewers and waste removal systems (CAP 2007). With their high population density, their large numbers of poor and elderly residents, their dense physical structure and their dependencies on infrastructure systems as well as their accumulation of material wealth, cities and towns are extremely vulnerable to the impacts of climate change (EEA 2009b). Moreover, the vulnerability of urban areas to climate change is also a function of social, economic and political processes. Proposed key components for vulnerability include (Dawson et al. 2009):

- Economic well-being and stability (e.g. standard of living; rate of urbanisation),
- Demographic structure of population,
- Institutional stability (e.g. institutional ‘memory’, corruption)
- Strength of and reliance on public infrastructure (e.g. health expenditure, communication infrastructure, financial, transport, and corporate systems, degree of centralisation)
- Global interconnectivity (e.g. trade balance, tourism),
- Natural resource dependence and regenerative ability of ecosystems, and
- Dependency on external energy, water, money etc.

Next to climate change, other drivers influence vulnerability of urban regions, including demographic development, changing consumption patterns, urban sprawl, land use changes, globalisation connected with side effects on human health such as air pollution and noise (EEA 2009a).

Since many factors influence the vulnerability of cities and urban areas to climate change, it is important that any vulnerability assessment defines carefully and explicitly the object of investigation and the measure of vulnerability being adopted. This will be informed by the purpose of the analysis, but also by more practical issues, such as data availability.

2.4 Adaptation activities of urban regions

The awareness on the need of climate change adaptation in cities and urban regions is currently increasing (Wilby 2007, World Bank 2008a): the European Commission as well as countries and regions are pushing to act on adaptation by creating adaptation strategies. The availability of EU funding for research and project implementation may, however, prove crucial in fast-tracking adaptation efforts. Adaptation can be expected to become more predominant in cities’ agendas in the near future, as the availability and credibility of data becomes more widespread and awareness rises.

The need for adaptation is requested by several stakeholders, in addition to the city councils. Bottom-up approaches of adaptation actions are common and have the advantage of providing valuable local knowledge for the analysis of the considered challenge. Nevertheless, top-down participation from the national or higher level is likewise important. The national governments may play a crucial role as a coordinator of regional strategies and a guarantor for the discussion and implementation of adaptation measures wherever necessary (Corfee-Morlot et al. 2009).

Internationally, many cities have developed comprehensive programs to reduce greenhouse gas emissions. A few leading cities such as London, Copenhagen, Rotterdam, have also conducted assessments of likely climate change impacts for their regions and are beginning to take action to reduce the vulnerability of their services and citizens to these impacts: Several cities have set priorities and got started in adaptation, especially in the areas of greatest concern – taking action to protect against future water shortages, flooding, heat waves and other climate related problems (CAP 2007). There is every reason for cities to begin incorporating concerns about climate impacts into long-lived infrastructure projects for energy, water, storm water, transportation, buildings, green corridors and waterfront or floodplain developments that are currently in the planning stages and are likely to be affected by climate change during their lifetime (CAP 2007), while simultaneously improving the energy and emission performance of the built environment (Corfee-Morlot et al. 2009).

Key questions are how cities will reduce health risks and secure the functioning of essential infrastructure for the provision of energy, transport, electricity and heating, waste and water management, health services, and avoid loss of biodiversity. Adaptation calls for a fundamental rethinking of urban design and management, and it should be "mainstreamed" in all related policies, including land use, housing, water management, transport, energy, social equity and health (EEA 2009b, EEA 2010a).

To cope with the climate conditions of the future, cities will have to find innovative solutions integrating technological and behavioural solutions**.** City authorities are in a unique position to engage local stakeholders and design locally tailored responses to climate change (Corfee-Morlot et al. 2009).

Several solutions are already at hand. There are a suite of adaptation ‘grey’, ‘green’ or ‘soft’ options available that can adequately be implemented at affordable costs to respond to climate change. ‘Green’ and ‘soft’ solutions can often provide low-cost solutions and there is usually enough knowledge for their implementation. High-tech and new solutions are usually supported and funded and require more knowledge, experience and training to be operated. Infrastructural technologies also offer adaptation opportunities in cities that adequately take into account the long-term spatial planning perspectives (EEA 2010a).

Lessons learnt from early adapters, such as London, New York, Boston, indicate that it takes leadership, persistence and a broad knowledge of urban systems and on how they interact with climate and each other, to get and keep adaptation on the agenda of cities and to devise and to implement adaptation strategies (CAP 2007). A recent OECD report (Corfee-Morlot et al. 2009) highlights the progress made to advance principals of good practice, including participatory governance; the existence of a strong analytical foundation for short and long-term planning; cost-effectiveness and economic efficiency; the consideration of distributional consequences and procedural equity; the use of a long term planning horizon; and policy coherence and feasibility.

3 Scoping vulnerabilities in urban regions/cities: What and who is vulnerable to what and when?

3.1 Vulnerability definition

In this study, the most authoritative and widely quoted definition of vulnerability in the context of climate change from the Fourth Assessment Report (IPCC 2007) will be used as a starting point:

"Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2007, p.883).

Exposure is the "nature and degree to which a system is exposed to significant climatic variations" (IPCC 2001). Changes in exposure are usually explored through climate models that demonstrate how, given certain assumptions, climate variables may change over time for a given area. Sensitivity is the "degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise)". Adaptive capacity is "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2007).

The IPCC definition has significant limitations (see for a detailed discussion Harvey et al. 2009, p. 15); most critically it does not define the form of the function, which relates the three components of exposure, sensitivity and adaptive capacity. Also the used terms are only vaguely defined and have some overlap. The IPCC concept in general has proven difficult to operationalise in practice (e.g. Patt et al. 2009a). The most challenging aspect of the vulnerability definition provided by the IPCC is the concept of adaptive capacity and how it is influenced by social, political, economic, technological and other components. There is considerable debate in the literature as to what constitutes adaptive capacity and how it might be recognised (e.g. Yohe and Tol 2002, Brooks et al. 2005, Vincent 2004). Since vulnerability is a concept mainly about future potential situations (Hinkel 2011), also its components needs to be described as prospective situations. However, it is important to consider experiences made and events happening in the past and at present to be able to evaluate future sensitivity and adaptive capacity of a learning system. For a further discussion, see section 4.1.

Adapting to climate change impact is also linked to disaster risk reduction (DRR). Therefore it is worth noting that the meaning of key terms such as 'hazard', 'exposure', 'vulnerability' and 'risk' differs within the climate change and the disaster risk community due to diverging departing points when developing their concepts (O'Brien et al. 2008).

With this in mind, it is important to be *transparent* and explicit about exactly what is meant by vulnerability in a given context to ensure stakeholders understanding in what will and will not be covered by any particular assessment or study. It is also important to be *pragmatic* about the approach followed in practice. Thus, when analysing the different socio-economic and biophysical components determining vulnerability in this study, we use the following distinguishing features for the three elements of vulnerability:

Exposure is determined solemnly by the variations of climate (e.g. temperature during a heat wave) and the likelihood of its occurrence independent of characteristics of the affected system; it may be represented as either long-term change in climate conditions, or by climate variability and its changes, including the magnitude and frequency of extreme events.

The *sensitivity* of a system under observation refers to its responsiveness. It is determined by its (structural) physical and socio-economic characteristics which are directly or indirectly influenced by climate variations and which are rather static and not easily changed (e.g. location, elevation, building structures, age structure of population).

The *adaptive capacity* of a system is formed by the system's potentials to adjust to climate variations including the ability to learn from experience or information and hence to reduce its sensitivity (e.g. availability of air conditioning). However, components determining sensitivity and adaptive capacity are not easily separated, since future sensitivity depends on current adaptive capacities and measures. Section 3.2 outlines the approach adopted for the purpose of this study.

Additionally, this study investigates the form of the function used to combine or aggregate the components of vulnerability, i.e. the ways used in literature to aggregate components for exposure, sensitivity and adaptive capacity to derive a vulnerability indicator (see chapter 4).

3.2 The vulnerable urban system and its components

When evaluating vulnerability, the vulnerable system itself and the expected adverse effects (threats) causing possible harm, including the possible type and extent of harm, need to be identified and made explicit. This should be informed by the objectives and purposes of the evaluation itself. The section on 'context and aim of the scoping study' outlines the purpose behind this report, the potential application of vulnerability indicators and target audiences. Since there are many factors that influence the vulnerability of cities and urban areas to climate change, this chapter (and the related annex 7.1) describes the urban system and more specifically who or what in a city or urban region is likely to be affected harmfully by which climatic threat (based on a literature review). The harm identified is clustered in three classes: harm to human health, economic losses and damage to ecological services.

The main vulnerabilities of cities and urban regions to climate change can be defined in form of "*climate change issues*" for European cities and urban regions as developed in Harvey et al. (2009). Such a climate change issue being a combination of (Figure 3):

- a **climate threat** (e.g. drought, heat waves, flooding, sea level rise, etc),
- a **European macro-region** (e.g. Mediterranean, central Europe, Baltic coast, etc.),
- a **sector, function or specific system** (e.g. forestry, human health, energy network, buildings, etc) and
- a **target group or group most affected** (e.g. elderly, land managers, outside workers, low income group, etc).

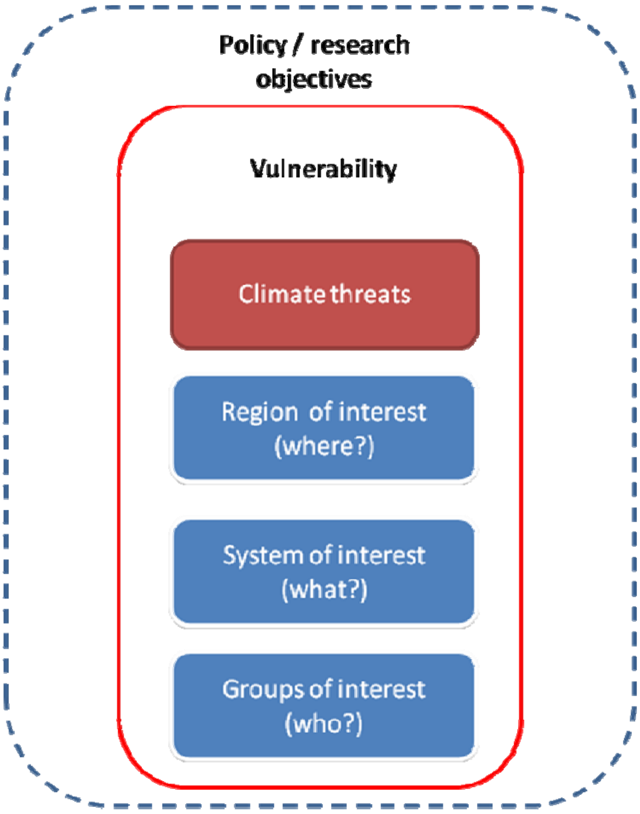

Figure 3. Graphical representation of the issue-concept.

The remaining part of this section outlines in more detail the threats, systems and groups of interest for this scoping study.

Climatic threats

Urban areas and cities in Europe are facing different *climate threats* (see introduction). The main climate threats which are considered in this study are:

1. temperature increase leading to heat waves
2. sea level rise influencing storm surges and salt water intrusion
3. heavy precipitation leading to fluvial and urban drainage floods
4. storms (wind, rain, thunder and snow storms)
5. decreased precipitation leading to water scarcity and droughts
6. climate impacts leading to natural disturbances, e.g. wild fires, pests
7. climate impacts leading to earth movements (avalanches, landslides, erosion)
8. climate impacts leading to increased human diseases

Geographic region

The vulnerability of urban regions is highly influenced by their *geographic situation*. European macro-regions[6] are areas from a number of different countries or regions associated with one or more

[6] DG Regional Policy, http://ec.europa.eu/regional_policy/cooperation/baltic/pdf/macroregional_strategies_2009.pdf

common features or challenges and likely to be exposed to similar climate threats due to geographic similarities. Functional regions may well overlap, so that a given location is in more than one macro-region. According to an assessment by the EEA (2008) biogeographic macro-regions in Europe facing similar climatic threats have been defined:

1. Arctic: decrease in Arctic sea ice coverage, Greenland ice sheet loss.
2. North-western Europe (North Sea Region and Atlantic Region): increase in winter precipitation, and river flow, northward movement of freshwater species.
3. North-eastern Europe (Boreal Region): less snow, lake and river ice cover, increased river flows, higher forest growth, northward movement of species, higher risk of damages by winter storms.
4. Central and eastern Europe: more temperature extremes, less summer precipitation, more river floods in winter, higher water temperature, increased forest fire danger, lower forest stability.
5. Mediterranean region: decrease in annual precipitation, and annual river flow, increase in water demand, more forest fires, higher risk for desertification, biodiversity loss and heat waves, more vector-borne diseases.
6. Coastal areas (Mediterranean Sea, Atlantic, North Sea, Baltic Sea, Black Sea): higher risks of coastal flooding, coastal erosion and salt water intrusion
7. Mountains: high temperature increase, less glacier mass and permafrost, higher risk of soil erosion, avalanches, rock falls and species extinction, upward shift of plants and animals.

If definitions and information on city types and their specific sensitivity would be available, these could be used here additional to the regional situation. Since this is not available, city characteristics such as building structures were investigated as part of the sensitivity or adaptive capacity components of the vulnerability indicators in 7.1.

Vulnerable systems

In general, the *systems of interest* in this study are those related to cities and urban regions (see introduction for definition). Cities are very complex and combine, in one geographical location, a large number of inter-related biophysical and socio-economic systems. The focal point of all urban systems is the preservation of health and wellbeing of the urban population. In the following, we differentiate between human health and the socio-technical health system, which is the institutional and organizational arrangement designed to protect human health.

Most systems are threatened by more than one climate change related impact and most climate change threats have influence on more than one system. Therefore, threats and systems are multiple connected (**Table 4**). For further information on the systems and the causes of their vulnerability see annex 7.1.1.

Table 4. Examples for the relations between urban systems and climate change related threats. (own evaluation based on BBSR 2009, IPCC 2007, World Bank 2008b).

Legend: The colour code represents *the predominant* impact to of a specific climate threat/issue on a specific system.

Colour	Effect
	Potential for infrastructural damage or impairment [7] *(angle: system physical damage)*
	Potential for reducing or interrupting the system's ability to function properly, including system overload and underuse[8] *(angle: system capacity and functionality)*
	Potential for negatively impacts on human health, social interactions or causing human casualties[9] *(angle: personal and not visible impact)*

[7] Does not apply to the following systems considered: Health, Governance and management, and Social.

[8] Applies to all the systems considered. When referring to 'soft' systems such as Social or Governance and management the system's functionality is understood as its ability to deliver its expected results.

[9] Applies to all the systems considered, but especially to Health, Food production & supply, Governance and management, Social, and Tourism.

Vulnerable systems in cities	Climatic threats / issues: Higher tempera-tures and heat wave	Sea level rise and storm surge-driven flooding	Sea level rise and saltwater intrusion into aquifers	Heavy precipitation and fluvial floods,, and erosion	Heavy precipi-tation and urban drainage floods	Decreased precipi-tation, water scarcity, drought	Wind storms	Wild fires	Vector- and water-borne diseases, atopic diseases
Energy supply	IPCC , WB BBSR 🔴🔵	IPCC 🔴		IPCC 🔴	IPCC 🔴	IPCC BBSR 🔵	IPCC, WB 🔴	IPCC 🔴	
Communication and information	IPCC, WB 🔴🔵	IPCC 🔴		IPCC 🔴	IPCC 🔴		IPCC 🔴	IPCC 🔴	
Transportation	IPCC BBSR 🔴🔵	IPCC BBSR 🔴🔵		IPCC BBSR 🔴🔵	IPCC BBSR 🔴🔵	IPCC 🔵	IPCC BBSR 🔴🔵	IPCC BBSR 🔴🔵	
Water supply	IPCC BBSR 🟢🔵	IPCC BBSR 🔴🟢🔵	IPCC BBSR 🟢🔵	IPCC BBSR 🔴🟢🔵	IPCC BBSR 🔵	IPCC BBSR 🟢🔵		IPCC 🔵	IPCC BBSR 🟢🔵
Sewage and drainage	BBSR 🟢🔵	IPCC 🔴🔵	IPCC 🔵	IPCC 🔴🔵	IPCC BBSR 🔵	IPCC BBSR 🟢🔵			IPCC 🟢
Solid waste	IPCC 🟢🔵	IPCC 🔴🟢🔵		IPCC 🔴🟢🔵	IPCC 🔴🟢🔵		IPCC 🔴🔵	IPCC 🔴🔵	
Buildings and built-up area	IPCC BBSR 🔵	IPCC 🔴		IPCC BBSR 🔴	IPCC BBSR 🔴	IPCC, WB 🔴	IPCC BBSR 🟢🔴	IPCC 🔴	
Urban green (areas) and biodiversity	IPCC BBSR 🔴🟢🔵	IPCC 🔴🟢🔵	IPCC 🔴🟢🔵			IPCC BBSR 🔴🟢🔵	BBSR 🔴🟢🔵	BBSR 🔴🟢🔵	
Health	IPCC BBSR 🟢	IPCC BBSR 🟢	IPCC BBSR 🟢	IPCC BBSR 🟢	IPCC BBSR 🟢	IPCC BBSR 🟢	BBSR 🟢	BBSR 🟢	BBSR 🟢
Food production & supply	IPCC 🔵	IPCC 🔴🔵	IPCC 🔴🔵	IPCC 🔴🔵	IPCC 🔴🔵	IPCC 🔴🟢🔵	IPCC, WB 🔴🔵	IPCC 🔴🔵	
Governance and management	BBSR 🟢🔵	IPCC BBSR 🟢🔵	BBSR 🟢🔵	IPCC BBSR 🟢🔵	IPCC BBSR 🟢🔵	IPCC BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵	IPCC BBSR 🟢🔵
Social	IPCC 🟢	IPCC 🟢	IPCC 🟢	IPCC 🟢	IPCC 🟢	IPCC 🟢	IPCC 🟢	IPCC 🟢	IPCC 🟢
Tourism (related economic system of the urban region)	BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵	BBSR 🟢🔵

The operability of one system often depends on that of other systems. As such impacts on or changes in one system usually do have important knock-on effects across the urban area. For example, most systems are directly dependent on the energy supply system, which is sensitive to different climate change related threats (e.g. floods, wind storms, wild fires). A failure in one critical system is likely to create chain reactions in other systems in form of positive feedbacks. This could lead to a complete breakdown of some urban systems, e.g. the motorized transportation system. Considering the interconnectedness *between* risks is equally important as understanding the nature of specific risks (e.g. WEF 2009, WEF 2010).

Vulnerable groups

From a social science perspective, vulnerability to climate change refers to the ability of *individuals and groups* to adapt to anticipated and unanticipated change as a consequence of shifting climatic conditions. In general, the ability to cope with climate change will be constrained by the personal constitution and the availability of resources, particularly information, knowledge, technology, financial assets, political power, social status, and personal and professional networks (Adger and Kelly 1999, Adger et al. 2006). Some people will have the resources to resist the threats, relocate and retain their livelihoods and maintain their social networks; whereas others will not (Carmin and Zhang 2009). Among the generally accepted characteristics influencing social vulnerability are age, gender, race, and socio-economic status. Other characteristics identify 'special needs populations' or those that lack the social safety nets necessary in disaster recovery, such as the physically or mentally challenged, non-native speaking immigrants, the homeless, transients, and seasonal tourists (Cutter et al. 2003; also see Stanley 2009). In general, the most common vulnerable groups in urban areas are (Carmin and Zhang 2009, Werg et al. in preparation, see also Table 5):

1. elderly
2. low income groups
3. disabled, sick
4. young
5. ethnic minorities

For instance, the elderly and infirm people may not have the financial or social resources, necessary to e.g. relocate to new housing after weather related destructions. Many of the poor urban inhabitants live in low quality residences, including those without adequate insulation or leaky roofs and windows (Carmin and Zhang 2009). Given that their health and nutritional status often is compromised, the poor, along with the sick, the very young and elderly, will be at the greatest risk from illness and death from heat and humidity (Kasperson & Kasperson 2001; also see Reid et al. 2009) and to the emergence of new disease vectors. Those who are socially isolated may have difficulties adjusting to the changes taking place around them while immigrants and foreigners who do not speak the national language may be unable to learn about impending issues or may be discriminated. For example, minorities in Eastern Europe often receive unfair treatment in times of disaster (Carmin and Zhang 2009). Studies included in Table 5 refer to industrialized countries worldwide. There are high correlations between the different vulnerable groups (e.g., low income and minorities). The high vulnerability of low income groups to heat waves is from particular relevance in the U.S. where poorly insulated buildings and air conditioning in private households are far more prevalent than in most of Europe. In contrast, affluent people who life in locations exposed to hazards, e.g. at the sea side or close to a river, carry the risk of loosing more economic wealth in absolute terms but because they are more often insured (Semenza et al. 1996). Therefore their relative vulnerability is expected to be generally lower than that of low income groups (Bailey and Kerchner 2007).

One of the most critical factors affecting individuals and families in urban areas is the quality and location of their residences. In particular, families who live in homes that cannot accommodate changes in temperature, storms, and precipitation will be at risk as will those living in properties situated in floodplains, coastal areas, or on steep slopes (Carmin and Zhang 2009). For instance, Walker et al. (2006) found disproportionate concentrations of deprived populations in zones at risk from sea flooding. Because the location of the residence influences the vulnerability to some hazards strongly, the above mentioned groups are not equally vulnerable to all climate threats. Therefore, even inside the same building the residents of rooftop flats and flats with windows facing South and West are more exposed to heat whereas the people living in the ground floor are more exposed to floods.

In identifying the most vulnerable individuals and groups it should not only be focused on the groups named before (elderly, low income groups, disabled, sick, young, ethnic minorities). Taking into account the various factors increasing vulnerability (e.g. unhealthy lifestyles, specific habits and attitudes, other stressors than climate change like air pollution) allows identifying individuals and groups that do not appear to be vulnerable at first sight (Werg et al. in preparation). For example, during storms and heat waves the mobile and active people who are often outside due to their professional duties (e.g. salesmen, policemen, construction workers, etc.) are also very vulnerable (Wilhelmi and Hayden 2010).

Table 5. Relation between vulnerable urban groups and climate change related threats.

(Werg et al. in preparation, based on (a) Baxter 2005, (b) Cohen et al. 2003, (c) Fekete 2009, (d) Gladwin and Peacock 1997, (e) Greiving 2006, (f) Harlan et al. 2006, (h) Knowlton et al. 2009, (i) Morrow 1997, (j) Morrow 1999, (k) Peguero 2006, (l) Reid et al. 2009, (m) Semenza et al. 1996, (n) Steinführer and Kuhlicke 2007, (o) Ueland, & Warf 2006, (p) Jonkman et al. 2009, (q) Eisenman et al. 2009, (r) Adeola 2003, (s) Green et al. 1994, (t) Tunstall et al. 2006, (u) Jonkman 2007, (v) Masozera et al. 2007, (w) Gerba et al. 1996, (x) Catapano et al. 2001, (y) Hunter 2003, (z) Benson et al. 2000, (aa) Satterthwaite et al. 2007, (bb) Smyth and Royle 2000, (cc) Phillips 1998).

(Note: The majority of the cited studies are of quantitative nature, i.e. the statements reflect statistical interrelations. For the few cited studies in the table that rely on reasoning of the authors or qualitative data, 'probably' precedes the statement. 'No reliable results' indicates that no studies could be found that report statistical results or sound qualitative data regarding the specific vulnerability of the particular group to the particular hazard.)

		Climatic threats / issues						
		Higher temperatures Heat wave	Sea level rise and storm surge-driven flooding	Heavy precipitation and fluvial floods	Heavy precipitation and urban drainage floods	Wind storms	Vector- and water-borne diseases, atopic diseases	Land slides
Vulnerable groups	elderly	High vulnerability due to physical fragility[e] (cardio-vascular diseases & respiratory conditions, diabetes)[l]; increased by social isolation[m]	More likely to die from direct physical impact (drowning); probably lack physical / financial resources for effective response during / after event [a), (j), (p]	High post disaster vulnerability: More often in need of emergency shelter[c), (n] (lack of social and financial resources)	No reliable results	Tend to be reluctant to evacuate / leave their homes despite warning[d]; lack physical and financial resources for effective response[j]	More likely to be affected by waterborne rotaviral infections (case fatality rate 100 times (i.e. 1%) higher than the general population in US)[w]	Likely to have posttraumatic stress in the aftermath of landslides (Sarno, Italy)[x]
	sick	Particularly high risk for those with renal & cardiovascular conditions, diabetes[h]	Post-flood morbidity (and mortality) is significantly higher for flood victims who suffer from pre-existing health problems[s) (t]		No reliable results	No reliable results	Immuno-compromised people are affected disproportionately by waterborne rotaviral infections (up to 50%)[w]	No reliable results
	disabled[q]	No reliable results	(Elderly) persons with disabilities more likely to die, probably due to lack of physical resource for effective response (move to higher floors)[u]		No reliable results	No reliable results	No reliable results	No reliable results
	young	Higher risk due to physical fragility (children 0-4)[h]	No reliable results	No reliable results	No reliable results	No reliable results	Probably more likely to be affected by waterborne diseases[y]	No reliable results
	low income groups	Higher vulnerability due to poorer health status[b]; more likely to live in warmer neighbourhoods with greater exposure to heat stress[f]	More likely to be located in vulnerable locations (applies also to some highly affluent people who prefer coastal estates)[j]; lack of transportation for evacuation[v]	High post-disaster vulnerability: less likely to hold insurance[n]; less educated: more often dissatisfied with damage compensation[c]		More likely to live in poorly built houses, insufficient financial reserves for purchasing supplies before / services after a storm event[j]; less access to transport for evacuation[i]	Probably more likely to be disproportionately affected due to limited access to sound health services (e.g. regular vaccination)[z]	Low- & middle income countries: more likely to settle in hazardous physical environment[aa], e.g. marginal land, hillsides[bb]
	ethnic minorities	More likely to live in warmer neighbourhoods with greater exposure to heat stress[f]	Less likely to live in flood prone coastal areas (Southern U.S.) (reduces vulnerability)[o]	More likely to live in flood prone / lower urban areas (Southern U.S.)[o), (r]	No reliable results	More likely to rely on information from peers, which can lead to ineffective disaster preparedness[k]	No reliable results	High post-disaster vulnerability of Latinos: difficulties in obtaining adequate and affordable housing[cc]

3.3 The urban 'climate change issues'

The most recent IPCC report (2007) provided an assessment of potential impacts across Europe for a number of sectors and systems. The EEA indicator-based assessment on the impacts of Climate Change on Europe (EEA 2008) and the Impact Assessment to the White Paper (EC 2009a) have built on the IPCC report to further develop the evidence base. By analyzing these main authoritative and recognised sources of information on climate change impacts at the EU level, Harvey et al. (2009) identified 52 climate change 'issues' (definition see section 3.2) of concern for Europe. Building on this initial assessment, the team of this project identified 10 issues to be particularly relevant for urban areas. Table 6 summarises the 10 identified urban climate change issues considered in this scoping study, identifying:

- the nature of the impact or threat,
- the urban system of interest,
- population groups of interest and
- European regions likely to be most affected.

Some systems (e.g. energy supply, transport, health) are especially vulnerable because multiple hazards threaten them. The operability of most systems depends on the operability of other systems; therefore a failure in one system, e.g. energy, will also create problems to others (see section 3.2 and annex 7.1.1). Since this chapter is supposed to be a summary it does not cover *all* possible interactions or combinations between the different systems. The focus is on systems, groups and regions of *primary* interest at the European scale. For example, while it is obvious that heat waves are not only an issue for the health sector, the majority of exiting work both in terms of research and policy developments has been in terms of human health. The consequences of heat waves are wide spread and cause disruption to the economy, society and the environment in multiple ways, including:

- Increased hospital admissions and pressure on care services;
- Psychological impacts, increased violence and social unrest (Simister and Cooper 2004);
- Water pollution caused by a combination of low water flow and heat;
- Water shortages (domestic, agriculture, industry, fire & rescue);
- Failure of transport networks due to buckling rails and overheating of train / tram power sources. Travellers marooned en-route;
- Failure of power supplies due to high demand for electricity for cooling purposes and overheating of electricity sub-stations, lack of cooling water as well as melting of wires;
- Increase in number and severity of wildfires (grassland & forest fires) and fires more generally (EPS 2009);
- Biodiversity, farming and forests suffered significantly; around €13bn was lost during the 2003 heat wave in the agriculture sector alone (COPA COGECA 2003).

Table 6. Urban climate change issues (based on Harvey et al. 2009).

Issue no.	Climate impact and related threat	Primary type of harm	Vulnerable systems	Most vulnerable population groups	Most vulnerable European regions	EEA impact indicators (from 2008 assessment)
1.	Higher temperatures and heat wave	Human health	Health, energy and water supply, information, transport, urban green (areas) and biodiversity	Children, elderly and sick people, low income groups, ethnic minorities, people working outdoors	All (IPCC: Mediterranean most affected)	1. Heat and Health 2. Heat waves in Europe (climatic) 3. Temperature extremes in Europe (climatic) 4. Health (economic impacts)
2.	Decreased precipitation, water scarcity and drought	Economic losses (human health)	Water supply, sewage and drainage, urban greens, bio-diversity, energy supply, food supply, social, health	Likely: Elderly, sick and disabled, low income groups, ethnic minorities (no reliable references)	Med. Region (IPCC 2007) and South-Eastern Europe (EEA 2008)	River flow drought, Riverflow, Public water supply and drinking water management
3.	Wildfires – higher temperatures, decreased precipitation	Loss of ecosystem services (economic losses and human health)	Urban green (areas) and biodiversity, health, buildings and built up area, energy and water supply, food supply, transport, social	Likely: Elderly, disabled and sick, infants, workers exposed to outdoor conditions (no reliable references)	All. According to all sources, the most significant effects will be in the Mediterranean	Forest fire danger
4.	Heavy precipitation, fluvial floods	Human health and economic losses	Health, buildings and built up area, energy and water supply, transport, information, sewage and waste, social	Elderly, disabled and sick people, ethnic minorities, low income groups	All flood plains. greatest impact in the North, Atlantic and Central European areas (IPCC 2007).	River floods (number of events) Precipitation extremes European precipitation
5.	Heavy precipitation, and urban drainage floods	Economic losses	Health, buildings and built up area, energy and water supply, transport, information, sewage and waste, social	Likely elderly, disabled and sick people, ethnic minorities, low income groups, low income groups (similar to flood victims)	All	n/a

6.	Sea level rise and storm surge-driven flooding	Economic losses (human health)	Buildings and built up area, health, transport, Water supply, sewerage and waste	Elderly, disabled and sick people, low and high income groups	Coastal areas. In particularly in the North, but also Atlantic and Mediterranean (EEA 2008).	Storms and storm surges in Europe, Coastal area (floods), Sea level rise
7.	Sea level rise and saltwater intrusion into aquifers	Economic losses	Water supply, food supply, biodiversity, urban greens	Likely people relying on groundwater, low income people (no reliable references)	Coastal areas	n/a
8.	Mass movements and erosion	Economic losses	Buildings, transport, energy supply, information health	Landslides: Elderly people, low income groups, ethnic minorities	Hilly regions, river valleys.	Soil erosion by water
9.	Wind storms	Economic losses (loss of ecosystem services and human health)	Buildings and built up area, Health, urban greens and biodiversity, transport, energy supply, information	Elderly people, low income group, ethnic minorities	All. Projections of changes in storm trends are highly uncertain. Greatest damage likely to be in North-west Europe and the North sea (IPCC 2007).	Direct losses from weather disasters
10.	Vector- and water-borne diseases, atopic diseases	Human health	Health, social, water and food supply	Children, elderly and sick people, low income groups	All	1. Vector-borne diseases 2. Water- and food-borne diseases

3.4 Summary and Gap Analysis

Section 3.4 summarises our current knowledge about vulnerabilities in European urban regions and provides an indicative analysis of where knowledge gaps exist. The level of information available for the extracted issues varies considerably (see annex 7.1 and

Table 7 for further information on the single issues). For practical reasons, we have focused on those issues which:

- have been assessed in detail in the literature (also in regard to urban areas),
- provide the necessary information on components determining exposure, sensitivity and adaptive capacities, and
- have been developed to some extent as relevant vulnerability or risk indicators already.

Table 7. Summary about the existing knowledge on vulnerability to different climatic threats (detailed information on the issues and the components determining exposure, sensitivity and adaptive capacity are in annex 7.1).

Climatic impact /issue	Extent of knowledge available on ...					Gaps
	Causes and effects on urban areas	Vulnerable systems, vulnerable groups and macro-regions	Components determining exposure	Components determining sensitivity	Components determining adaptive capacity	
Higher temperatures, heat wave and health problems	Intensively studied and well known effects	Identified (focus on vulnerable groups and health damage)	Clear causes, past and projected data available	Intensively studied and well known components, past data available	Suggestions exist, but little data available, no projections	Future changes in S and AC difficult to project
Decreased precipitation, water scarcity and drought	Studied, but less in urban areas	Identified, but less in urban areas (focus on sectors and vulnerable systems, mainly in the Med., economic damages)	Clear causes, difficult reaction chain, past data available, but difficult to project	Intensively studied, very many and different components, past data available	Suggestions exist about adaptation measures, but little quantitative data available, no projections	Mainly studied for agriculture, tourism, biodiversity, indirect effect on cities is little researched
Wildfires	Studied, but less for urban areas	No focus on specific groups or systems, mainly Mediterranean, economic as well as health damages	Clear circum-stances, difficult reaction chain, past data available, but difficult to project	Components are identified (related to topography, fuel load), none specific for urban areas	Suggestions available related to mitigation of fires and protection before and during the fire	Urban areas are not in focus of the assessments although affected.
Heavy precipitation and fluvial floods	Intensively studied and well known effects	Identified (vulnerable groups and systems, health and economic damage)	Clear causes, difficult reaction chain, past data available, but difficult to project	Intensively studied, very many and different components, past data available	Few suggestions exist, but little data available, no projections	Vulnerable groups difficult to determine, difficult projections
Intensive precipitation and urban drainage floods	Studied and well known effects	Identified (drainage system, health and economic damage)	Clear causes, difficult reaction chain, past data available, but difficult to project	Little studied, few important components, past data available	Suggestions exists regarding increased efficiency of urban drainage	Impacts depend on local circum-stances and are difficult to estimate and to predict
Sea level rise and storm surge-driven flooding	Intensively studied and well known	Identified (focus on coastal regions and	Clear causes, past and projected data available	Intensively studied, many and regional variable	Suggestions regarding general adaptive	Vulnerable groups are not determined in detail, socio-

	effects	economic damage)		components, past data available	capacity and adaptation options	economic factors are little investigated
Saltwater intrusion into aquifers	Studied, but less in urban areas	Identified, but less in urban areas (focus on systems and coastal region, economic damages)	Clear causes, very difficult reaction chain, but projections difficult	Studied, components are identified, but difficult to project	Few adaption options related to water uses and management exist,	Only few data about geographic distribution of the impact available
Mass movements and erosion	Studied, but not specific for urban areas	No focus on specific vulnerable systems or groups, mainly mountains, and on economic damages	Complex causes, very difficult reaction chain, past data available, but very difficult to project	Suggestions exists related to geo-physical structures, weak link to urban areas	Only generic suggestions about adaptation measures exist, weak link to urban areas	Urban areas are not in focus of the assessments (effects might be indirect)
Wind storms	Studied, mainly in North and Western Europe	Identified, focus on vulnerable systems and economic damages	Clear causes, difficult reaction chain, past data available, not possible to project	Some components are identified related to built structures	Some suggestions exist, very few	Occurrence, strength and effects of storm is difficult to project
Vector – borne and other diseases	Studied, but not specific for urban areas	Suggestions exist, focus on vulnerable groups and health damage	Difficult reaction chain, past data available, but difficult to project	Intensively studied, very many components, past data available	Suggestions exist, but little data available, no projections	Urban areas are not in focus of the assessments (effects might be indirect)

In general, the knowledge about vulnerable groups, systems and macro-regions can be summarised:

- While there is much general information concerning the vulnerability of key systems of interest available, we often lack the means of estimating the impact of single threats to a single system. One reason is that the vulnerability of one system depends also on the operability of other systems. Therefore, it is conceptually and methodologically challenging to separate urban vulnerability into constituent causes. In other words: to what extent is any given outcome the result of a particular threat?

- There is some specific and reliable information available on vulnerable groups. Studies on social vulnerability have increased in the last years, which are often not specific for urban areas and single threats but have a general focus. It is often assumed that some groups are vulnerable to different threats (e.g. elderly, disabled, low income etc.) because of their limited mobility, difficulties to inform or to warn them, or their missing social network. The scientific proof for these assumptions is often hard to find.

- Some threats are clearly connected to specific macro-regions, others less. Therefore, the vulnerability of different macro-regions can only be compared in regard to specific and relevant threats. The vulnerability of cities to a specific threat might be compared across macro-regions (although it might differ what is experienced as threat in the different regions and therefore the threshold might need to change), but the general vulnerability of cities should only be compared in regions facing similar threats.

The gaps in knowledge about exposure, sensitivity and adaptive capacity of urban system in regard to impacts of climate variation are:

- For most threats, the specific conditions causing exposure to climate change and the general effects of climate variations are known. However, the detailed cause-effect chains of many climate change impacts are still not understood. Often the focus of research has not been on urban areas. Past data on exposure variables is available, but projections at the necessary scale are most often difficult to achieve.

- The sensitivity of system depends on many special characteristics (e.g. urban design, building structure, age structure), which are often not directly linked to a climatic threat. Therefore, many suggested components seem to be plausible but it is difficult to decide which components are the most important ones. At European level and for cities, past data for sensitivity components is often available but future data is difficult to achieve.

- Adaptive capacity depends on various components with very different data available. For example gross domestic productivity (GDP) or education level of population is available at European level, whereas sector or impact specific adaptive capacity information require more sophisticated data extraction such as e.g. availability of air condition or existence of early warning systems for floods. Future projections on adaptive capacity are almost not available.

4 Scoping vulnerability indicators for urban regions

4.1 Introduction to vulnerability assessment by indicators

After having set the conceptual frame for vulnerability assessment and identification of the main climatic threats, vulnerable systems and population groups of concern in European urban areas in chapter 3, this section deals with the methodologies on how to *measure* and *compare* the vulnerability of cities to climate change.

There is no agreed integrated metric on how to quantify regions' or urban areas' vulnerability to climate change. Since vulnerability is a theoretical concept, it cannot be measured directly in a way an observable phenomenon such as temperature can be measured (Hinkel 2011, Kienberger et al. 2009). The most common way to overcome this constraint and to make the concept of vulnerability operational is to use indicator(s). Indicators are a kind of measure - they are generally sets of information used to determine the status quo or changes of a characteristic of a system.

Indicators should be measurable, accessible, not redundant, transferable and easy to be applied in practice (Lane et al. 1999, Birkmann 2006). Depending on the context and the purpose of the envisaged vulnerability assessment, these indicators may be of quantitative character. But they may also embrace qualitative criteria or broader assessment approaches to allow for the integration of aspects, such as the institutional or cultural vulnerability (Birkmann 2006, Schneiderbauer 2007).

There are several cross-cutting issues when developing indicators for assessing vulnerability to climate change:

- The approach chosen for indicator development and indicator's components aggregation is always directed by the context and the purpose as defined by the user.
- In practice all approaches to operationally assess vulnerability need to consider the availability of data as the primarily limiting factor. Easy data access often allows for a repetitive update or a transferability of the vulnerability assessment whilst tedious data collection often result reveal information of high complexity and greater significance.
- Vulnerability describes the potential of future harm and hence possesses a forward-looking aspect (Hinkel 2011). However, vulnerability indicators shall be simple by definition and often based on past data only. Some indicator components point out current potential of future harm (e.g. employment rate, income, population structure). Less frequently used components indicate the current rate of change towards future harm (e.g. sea-level rise, population growth, inflation rate) (Hinkel 2009).
- The difficulty to quantify vulnerability and its components raises the question of how to validate the results of a vulnerability assessment and how to benchmark vulnerability indicators for comparable contexts (Schneiderbauer 2007, Füssel 2010a).

In order to cover the various aspects of the vulnerability concept, a vulnerability indicator is usually the result of the combination and aggregation of a number of sub-indicators or indicating components (Birkmann 2006, Kienberger et al. 2009). Therefore, after having defined the focus and rationale of the assessment (e.g. regarding impact, sector and system of concern, scale, purpose of the work, etc.) two principal steps remain for the development of a vulnerability indicator (Hinkel 2011):

1. The selection of indicating variables (or sub-indicators)
2. The aggregation of these indicating variables (or sub-indicators) – this step is not mandatory.

(For detailed discussion about indictors and their composition see for example OECD 2008, Saisana et al. 2005, Gallopin 1997; for detailed discussion about the working steps to develop vulnerability indicators see for example Birkmann 2006, Schröter et al. 2004b, Patt et al. 2009b, Füssel 2010a, Hinkel 2011, Hiete and Merz 2009.)

Indicator development

Three broad approaches for indicators development, including selection and aggregation of indicating components, can be distinguished (Harvey et al. 2009, Hinkel 2011):

- Deductive (based on theory)
- Inductive (using statistical, empirical relations)
- Normative (using expert knowledge)

The *deductive* approach is theory-driven and uses existing scientific knowledge in form of frameworks, theories or models about the system considered to generate a list of components. Examples are the social vulnerability index (SVI) developed by Adger and Vincent (2005), the ATEAM approach to assess the vulnerability of European regions to climate change (Schröter et al. 2005) and the so-called vulnerability-resilience indicators of Moss et al. (2001) or Yohe et al. (2006). In the context of vulnerability to climate change, the deductive approach suffers from limitation of the existing scientific knowledge about the vulnerability of social-ecological systems to general frameworks. A general shortcoming of the deductive approach is that it supports the selection of components but it does not provide any arguments for their aggregation into an indicator (Hinkel 2011).

The *inductive* approach is based on statistical models that explain observed impacts through indicating components. Peduzzi et al. (2002) and Dilley et al. (2005) are two prominent examples stemming from the risk / disaster community that attempt to use inductive methods to identify countries most at risk to natural hazards. National-level vulnerability indicators in the context of climate change have been developed by Brooks et al. (2005), Briguglio (1995) and Tol and Yohe (2007). Main constraint of the inductive approach is the data availability which is in particular a limitation for certain impacts, namely slow-onset hazards. However, this approach might be feasible at local scale in case that only a well-defined fraction of the system is considered by few variables and there is extensive data available.

The *normative* approach is based on subjective individual or collective expert opinion. It has widely been applied for the development of indicators for various purposes. The most prominent example is the selection of indicator components for the Human Development Indicator (HDI). A world 'Risk Vulnerability and Adaptation Index' which is currently under development and supported by the United Nations University will use normative approaches for the aggregation of sub-indicators

(Birkmann 2010, personal communication). Kienberger et al. (2009) based their social vulnerability study considering floods on normative stakeholder opinions for selecting components as well as for aggregating them. The disadvantages of the normative approach are the time and resources required for application and the limitation in transferring indicators to other regions. However, the integration of expert knowledge usually provides support in weighting and aggregation of indicator components and improves the acceptance of results.

Most applied vulnerability indicators make use of a combination of two or all three of the above listed approaches. In any case the final selection of indicators always requires the consideration of data availability as one of the main limiting factors of all approaches.

The most prominent approach to derive climate change vulnerability indicators is to select indicator components representing exposure, sensitivity and adaptive capacity of a system (in regard to a specified threat). This approach follows the IPCC vulnerability definition. There is no guideline or agreement on how to aggregate or combine the variables of the individual factors and there is a wide range of ways that have been applied in recent vulnerability studies (see for example Schröter et al. 2005, Zebisch et al. 2005, Birkmann et al. 2010).

Indicator aggregation and composition

The two main forms of indicators used in policymaking are aggregation and composition. An aggregated indicator combines a number of components defined in the same unit, for example the Gross Domestic Product (GDP). A composite indicator combines a number of components measured in different units into a single number with a common unit. For example, normalised measures of life expectancy, literacy, educational attainment, and GDP per capita are used to produce the Human Development Index (Harvey et al. 2009). Normally, in the case of indicators for vulnerability assessment and their mostly very heterogeneous components, one has to deal with the latter case. In addition, the vulnerability assessment to climate change may be based on both future scenarios (for example to quantify temperature increase) and measurements of the current status of sensitivity and adaptive capacity.

Levels of aggregation

The degree to which aggregation and composition should be implemented is determined by the aim and the end-user of the vulnerability assessment. If the comparison of results between regions or systems is required a certain degree of summation needs to be applied, which always implicates a loss of information. If the objective is to scrutinise vulnerability at fine scale in a case-specific way an in-depth analysis maybe appropriate that usually does not allow for comparison. A possible trade-off is to compose components whilst keeping (and communicating) the underlying information at the same time.

Due to the strong socio-economic component of vulnerability, it is often necessary to integrate data sets from many different sources that vary in format, scale and by their way of acquisition. In the absence of a complex integrated quantitative model that represents all the linkages and relationships between such data, combining them in a meaningful way is difficult (Preston et al. 2008).

The complex structure of the vulnerability assessment frameworks often requires hierarchical aggregation: the aggregation or composition of indicator components at various levels (see for example Schröter et al. 2005, Hiete and Merz 2009). In the context of climate change and the IPCC framework variables could for example be aggregated at factor sub-levels (e.g. economic adaptive capacity and institutional adaptive capacity) at factor level (exposure, sensitivity, adaptive capacity) and at general vulnerability level. The aggregation of sub-levels to one single vulnerability value is difficult to justify scientifically and leads to a loss of transparency.

Normalization

Before aggregating the values of components into an overall composite indicator value, the component values must be normalised to create a common measurement unit. Common normalisation methods include ranking, standardisation, min-max method or categorical scales. All methods have their specific advantages and disadvantages which have to be balanced considering the context and purpose for which they are applied. For a detailed discussion of normalisation methods see for example OECD (2008).

Weighting

Weights express the contribution and relative importance of the individual indicator component. The elicitation of weights requires a deep understanding of the theoretical vulnerability framework (Hiete and Merz 2009). However, the existing theories, models and frameworks (including the IPCC concept) usually do not provide any arguments about how various components should be weighted when aggregated. Therefore, most vulnerability assessments use either normative arguments by involving expert/stakeholder opinions or are data-driven or a combination of both. The data-driven approach is solely based on the structure of the composed datasets. Since there is little information provided by the theories and frameworks on the process of weighting and due to the difficulties to judge the importance of single components, in a number of studies equal weighting is applied (for example in the UN's Human Development Index, UNDP 2007)).

Weighting methods include multivariate statistics, data envelopment analysis (DEA), benefit of the doubt approach (BOD), unobserved components model (UCM), budget allocation process (BAP) and Delphi method, public opinion, multi criteria analysis (MCA) or analytic hierarchy process (AHP) and conjoint analysis (CA), most of them are discussed in OECD (2008).

The most commonly used methods that follow the data-driven approach are Factor Analyses, which support the reduction of indicator components. Here special attention has to be paid to the fact that these (and the majority of other multivariate statistical methods) require metric scale level for the input data. Successful examples for the application of statistical are the Social Vulnerability indices by Clark et al. (1998), Cutter et al. (2003) and Fekete (2009).

Most studies use normative approaches relying on expert knowledge for weighting. Experts' or stakeholders' opinion can be acquired and integrated in more or less structured form. Finding an agreement on how to weight indicating variables in the complex context of vulnerability assessments to climate change amongst a group of individual experts is a challenge for those attempting to develop an indicator. A number of methods, such as MCA, AHP and Delphi, support this process and have been applied successfully in recent studies (e.g. Schmidt-Thomé 2006, Birkmann (personal communication) 2010, Kienberger et al. 2009, Cardona 2005a).

The issue of scale

Vulnerability is scale-dependent, across both time and space. The definition of temporal and spatial scale in the beginning of a vulnerability assessment is crucial for the choice of indicator components. The choice of variables at the various scales is tightly connected with data availability and methods applied to acquire those data. This is particularly true for data describing the socio-economic characteristics of a system. In a simplified way and only pointing out tendencies, Figure 4 allocates some characteristics of vulnerability indicators and related data needs to the spatial scales, at which they are predominantly applied. For a detailed discussion about scale issues in vulnerability assessments see Fekete et al. (2009).

Regarding the temporal scale, the IPCC (2007) definition of vulnerability does not differentiate between current and future vulnerability. Vulnerability is mostly understood as a measure for future harm (Hinkel 2011). Future in this understanding is beginning in the next second and based on past and current experiences, which makes it difficult to differentiate explicitly between current and future vulnerability. Because of data limitations, most vulnerability assessments use only past data, and only few use also trends or projections of single components into the future. Thus, they are mainly concerned with current climate variations but have the potential to consider also long-term future climate change effects.

In general it can be stated that the limitations in data availability at coarser spatial scale call for the use of aggregated and standardised data provided by authorities at state or national level. These typically quantitative data are usually provided consistently over long time periods and allow for comparisons between areas of interest or systems and for frequent update of the indicator values. Assessments at a coarse scale highlight the overall significance of climate change impacts, enable the comparison of regions and provide information for central governments' policies, e.g. for providing money or other form of support (Torresan et al. 2008).

At local scales the amount of data available is usually high and of more complex and less standardised type. Assessments at a fine scale based on these data provide an accurate distinction of information and allow identifying specific vulnerable areas or sectors. They are able to unveil root causes of vulnerability and can be used for land use management and adaptation planning. Complexity and singularity of these datasets may hinder comparison and cause high costs for frequent update of indicator values. Certain methods to collect data (e.g. participatory approach) can only be applied at local level.

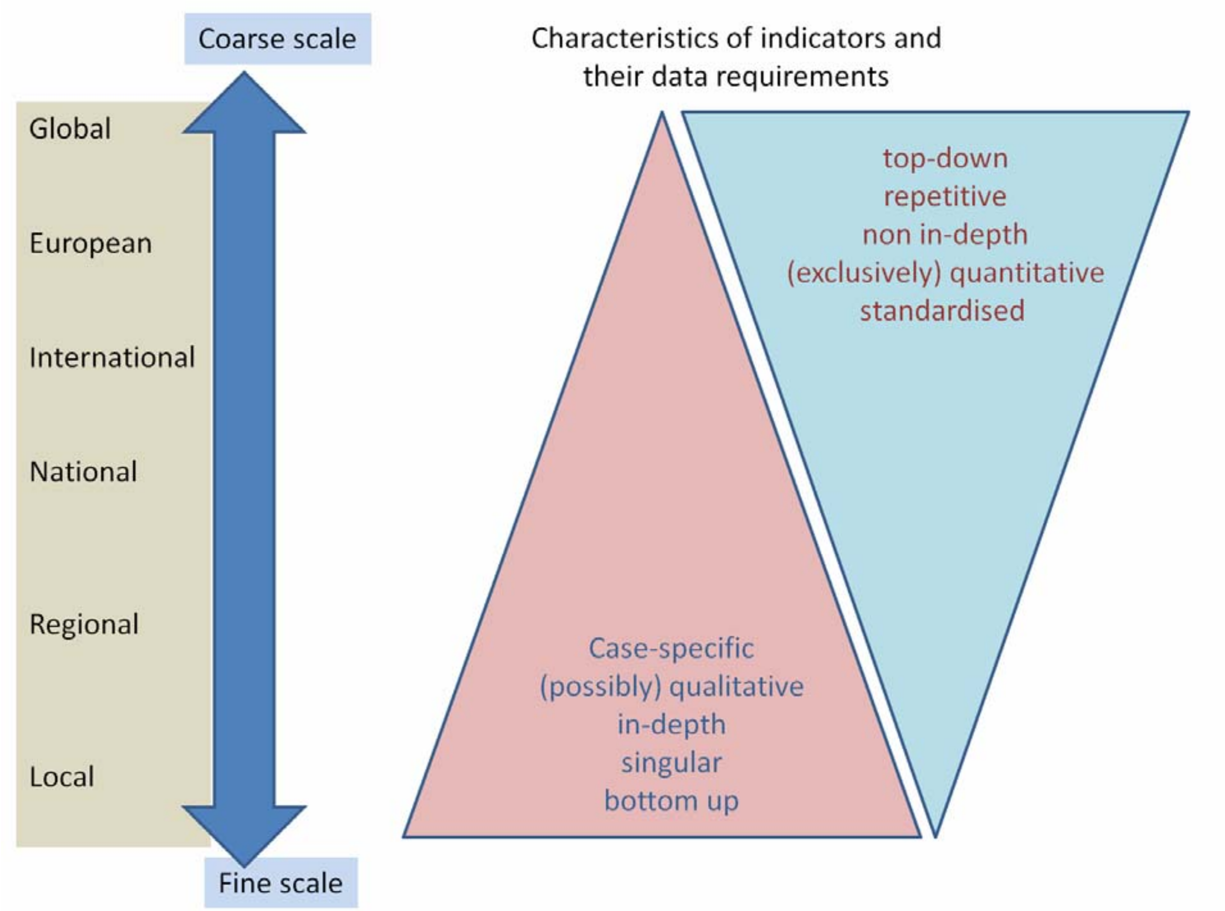

Figure 4. The relation of vulnerability indicators and related data to spatial scales.

Assessments at coarse scale are more likely carried out following a top top-down, due to limited data availability they are based on quantitative data. Data standards allow for comparison and repetition. Studies at fine scale are more often bottom-up steered. The data availability allows for in-depth analyses and the acquisition of qualitative data is possible. Complexity and singularity of datasets hinder comparison and frequent update of indicator values.

The results of vulnerability assessments

The results of vulnerability assessments need to be evaluated, further exploited and communicated with consideration of their strengths and limitations. Usually the outcomes of vulnerability assessments cover only partly the information required for decision making aiming at reducing the adverse impacts of climate change.

Due to the impossibility to measure vulnerability directly and as a result of the lack of a common metric (i.e., estimates of impacts in dollars) for quantifying it, the greatest value of vulnerability assessments might be an increase of the awareness of vulnerability as a crucial fact and the identification of vulnerability hot spots (e.g. of ecosystems, part of the society or in spatial terms). As basis for decisions on concrete measures to reduce vulnerability, the important information is collected at sub-indicator level and a composed overall vulnerability value is rather meaningless (Adger and Vincent 2005). Involving stakeholders and potentially affected populations in the process of generating vulnerability assessments increases the acceptance of the results and of consequential decisions on reduction measures (Preston et al. 2008). An aggregation of sub-indicators components to one vulnerability score for a specific impact only makes sense if comparison or ranking is the final goal. A direct comparison of vulnerability scores for different threats is even more challenging due to the lack of a common quantitative metric and information regarding the magnitude of the impact in terms of socio-economic and ecological damages (Preston et al. 2008).

The interpretation of the results of vulnerability assessments requires particular caution. It is important to be aware that vulnerability reflects potential susceptibility to harm but not any likelihood or magnitude of real future events. Vulnerability estimates should be interpreted in a relative rather than an absolute context (Preston et al. 2008, Schneiderbauer 2007). In contrast to concrete hazard management plans, vulnerability assessments provide information on issues that require further examination and investigation (Preston et al. 2008).

4.2 Currently existing threat specific vulnerability indicators

The literature and projects were scanned for existing vulnerability indicators for the identified urban issues and analysed based on the IPCC definition of vulnerability assuming that they should include components for exposure, sensitivity and adaptive capacity and that they explain the way of aggregating these components (summary in Table 8). See annex 7.1 for detailed information on vulnerabilities and existing vulnerability indicators, including general and threat specific vulnerability indicators.

Hazard specific vulnerability indicators for or transferable to urban areas were found for

1. Higher temperatures, heat wave and health problems
2. Decreased precipitation, water scarcity and drought
3. Wildfires
4. Fluvial floods, flood claims and health effects of flooding
5. Intensive precipitation and urban drainage floods
6. Sea level rise and storm surge-driven flooding

Most urban specific indicators have been developed for heat wave and fluvial floods. For wild fires and urban drainage flood only one research group could be identified having developed vulnerability indicators, although there are hazard maps for wildfires indicating past occurrence and biophysical sensitive areas. Sea level rise related threats have been investigated mainly as regional threats focussing on biophysical factors and less on socio-economic factors influencing the vulnerability of coastal regions. But some others also include socio-economic values, thus these studies are applicable for urban areas. Indicators found for drought and water scarcity are also not specific for urban areas but they include socio-economic sensitivity and adaptive capacity components and are thus transferable to urban areas.

For some other climate related threats, indicators in form of an impact, sensitivity or risk map exist (e.g. sensitivity maps for mass movements, impact maps for wind storms, maps of the potential establishment of tiger mosquito). However, because they are not directly linked to urban areas and do not integrate exposure and/or adaptive capacity components, they have not been assessed here.

For some other issues, no indicators or maps at all could be identified. Thus, we did not include those either:

1. Saltwater intrusion into aquifers
2. Wind storms
3. Mass movements and erosion
4. Vector –borne and other diseases

Table 8. Overview on existing vulnerability indicators.

Existing indicators	Details E – exposure, S – sensitivity, AC – adaptive capacity	Link to annex	Evaluation
Climatic threat/ issue: Heat wave: Higher temperatures, heat wave and health problems			
Components influencing the vulnerability of European populations to heat waves (Harvey et al. 2009).	E: 2 components (Warm Spell Duration Index; tropical nights); S: 2 components (age classes, age > 65 yrs); AC: 2 components (GDP, education level); Not aggregated.	Chap. 7.1.2, page 129	The proxy components used differ a lot, even those used for exposure, although they describe common and well known phenomena. The components relate to different spatial scales and different purposes of the vulnerability assessment done. They are mainly based on literature review, not on own statistical analysis of heat related damages data. The components considered do not take account of possible effects of heat waves on infrastructures, e.g. the effect of increased use of air conditioning on the energy demand. The aggregation methods vary: they are either too simple or too complex for an easy transformation to European level. There is no evaluation or validation of the proposed indices. Only one study analysed the influence of the single component by a kind of
Regional vulnerability indicator for heat waves to support the adaptation strategy of North-Rhine Westphalia, Germany (Kropp et al. 2009)	E: 1 component (heat wave days); S: 3 components (impervious surface, population density, age > 65yrs); AC: none; Aggregated by Fuzzy logic under use of thresholds	Chap. 7.1.2, page 129	
Cumulative heat vulnerability index for the USA to create maps for comparison and to give guidance at regional (county) and national scales for further analysis and intervention (Reid et al. 2009)	E: none; S: 5 components (race, age ≥ 65, living alone and age ≥ 65, diabetes, area without vegetation); AC: 5 components (poor, education level, living alone, without central or any air conditioning); Aggregated by principal component analysis.	Chap. 7.1.2, page 129	
Heat related risk assessment and a generic framework for risk management in Greater Manchester and Lewes (Lindley et al. 2006)	E: 1 component (daily max. and min. temperatures); S: 5 components (Urban Morphology Types, age > 75, age < 4, population health, residence dependency); AC: none; Normalised in classes, aggregated by unweigted addition.	Chap. 7.1.2, page 129	

Neighbourhood-level heat vulnerability assessment for the city of Toronto to assess cartographic design decisions in creating heat vulnerability maps (Rinner et al. 2010)	E: 1 component (surface temperature); S: 19 components (related to dwellings, income, specific population groups, age classes) AC: partly included in S Aggregation by specific multi criteria and cluster analysis methods.	Chap. 7.1.2, page 129	sensitivity study. A comparison of the results of different indices is missing.
Vulnerability Indicators for Extreme Heat and Human Health for the Sydney Coastal Councils Groups region to initiate a dialogue among researchers and stakeholders and a bottom-up assessment of local governments. (Preston et al. 2008)	E: 4 components (present January maximum and minimum, present days > 30 °C, change in average DJF maximum temperature in 2030) S: 8 components (Land use, population and road density, housing as multi-unit dwellings, age, projected population growth to 2019) AC: 13 components (internet access, home loan, home ownership, household income, council expenses, >12yrs education, non-English speaker) Aggregation by summation of components values for each element, scoring, weighting based on expert values and summation of the elements values for vulnerability indicator.	Chap. 7.1.2, page 129	
Climatic threat/ issue: Decreased precipitation, water scarcity and drought			
Indicators for U.S. water resources to investigate the integrated impacts of potential global warming (Lane et al. 1999)	E: 2 components (climate and economic scenarios, runoff ratio); S: 3 components (storage vulnerability, hydropower, water quality, coefficient of variation, dependence ratio) AC: 5 components (consumptive use, relative poverty, import demand ratio, withdrawal ratio) Only graphical aggregation as percentage of thresholds.	Chap. 7.1.3, page 137	The proposed indicators can also be applied to urban areas, but they are very general.
Indicators of vulnerability to climate change to inform the pertinent political debate on international adaptation funding within the framework of the UNFCCC (Füssel 2010b)	E: 3 components (median and standard deviation of projected change in precipitation, median of the projected change in runoff); S: 3 components (current population-weighted precipitation, renewable water resources per person, water use ratio); AC: 2 components (households with improved water supply or with improved sanitation); No aggregation suggested.	Chap. 7.1.3, page 137	

Climatic threat/ issue: Wild fires			
Vulnerability Indicators for Bush Fires for the Sydney Coastal Councils Groups region to initiate a dialogue among researchers and stakeholders and a bottom-up assessment of local governments. (Preston et al. 2008)	E: 6 components (present January maximum temperature, present days > 30 °C, annual rainfall average and 10th percentile, change in average DJF maximum temperature and rainfall in 2030) S: 7 components (Land use, vegetation cover, primary production, slope, aspect, population and road density) AC: 11 components (internet access, home loan, home ownership, household income, council expenses, >12yrs education, non-English speaker) Aggregation by summation of components values for each element, scoring, weighting based on expert values and summation of the elements values for vulnerability indicator.	Chap. 7.1.4, page 141	
Climatic threat/ issue: Fluvial floods, flood claims and health effects of flooding			
Components influencing vulnerability of European urban areas to river flooding to raise awareness of river flooding risk and to identify hotspots for more detailed analysis (Harvey et al. 2009)	E: 2 components (river flows, river floods); S: 1 component (population density); AC: 3 components (GDP, education level, money spend on flood protection); No aggregation suggested.	Chap. 7.1.5, page 144	There are two different foci of the existing vulnerability indicators: social components to identify vulnerable groups and geographical components to identify vulnerable buildings structures. To identify vulnerable groups many different components are used with different levels of detail: from population density to very specific household types and age classes. Most of these specific data is probably only available regionally (census data). Only one assessment integrates social hot spots e.g. schools, hospitals) and only two ecological values (e.g. vulnerable biotops). The choice of components is based on literature knowledge, but the appropriateness of a single component and the
Remote sensing based vulnerability assessment for Cologne and Dresden to present remote sensing potential for vulnerability assessment (Wurm et al. 2010)	E: 2 components (river flow, digital terrain model) S: 3 components (land use, urban building structures, population of city districts); AC: none Aggregation by a simple combination of the components.	Chap. 7.1.5, page 144	
Vulnerability of municipalities population to floods to provide detailed information for flood danger plans, adaptation support and evacuation plans (Birkmann et al. 2010)	E: 1 component (flood threatened area); S: 3 components (population in city districts buildings and storeys, household types); AC: 4 components (household income, rented dwellings, duration of stay in the flat, expectation about being flooded); Aggregation by adding different components without weightings.	Chap. 7.1.5, page 144	

Social vulnerability index in context to river-floods in Germany (Elbe and Rhine river valleys) to generate information about people potentially flooded (Fekete 2009)	E: none S: 3 components (age >65 yrs, population density, housing type); AC: 3 components (living space per person, (un)employment ratio, education level) Aggregation by component analysis and regression analysis to derive 3 most sensitive parameters (fragility, region, socio-economic conditions), which were combined to an index.	Chap. 7.1.5, page 144	combined indicators are not evaluated or verified. The aggregation methods vary from simple summation with equal weights to statistic methods, e.g. principal component analysis, and to sophisticated multi criteria analysis. Again, no clear framework or methodology to select and aggregate the indicators can be identified.
Social Flood Vulnerability Index (SFVI) for communities, e.g. Manchester and Maidenhead (Tapsell et al. 2002)	E: none S: 3 components (long-term sick, single parents elderly above 75); AC: 4 components (unemployment, overcrowding, non-car ownership, non-home ownership); Aggregation by simple weighting and summation the components in an index. The index was classified in 5 bands.	Chap. 7.1.5, page 144	
Integrated urban flood risk assessment for Leipzig (Meyer et al. 2009, Kubal et al. 2009)	E: 1 component (depth of inundation); S: 11 components (land use, classification of buildings, land values, affected population and special population groups per building, social hot spots, contaminated sites, soil erodibility , oligotrophic biotopes, protected biotopes, vulnerable trees); AC: none; Aggregation by multi criteria assessment to derive different risks (social, economic, land value, ecologic).	Chap. 7.1.5, page 144	
Social vulnerability indicators for flood risks in Manchester (Kazmierczak, in preparation)	E: 1 component (flood risk areas and land use); S:26 components (related to households structure, health, age classes, income level, education level, population groups); AC: included in the S components; Aggregation by principal component analysis to reduce the components to 4 components (poverty and poor health; ethnic minority and transient populations in high density housing; families with dependent children; elderly populations).	Chap. 7.1.5, page 144	
Spatial vulnerability units for socio-economic flood modeling (Kienberger et al. 2009)	E: none S: 6 components (with more sub-components) (households and building uses, infrastructure length, assets, sensitive land covers age distribution, employments) AC: 7 components (with more sub-components)	Chap. 7.1.5, page 144	

	(workforce in different economy sectors, size of companies/workplaces, ecosystem integrity of sensitive areas, distance to health facilities and roads, early warning system available, origin of population, education level) Aggregation based on multiple criterion analysis and on expert opinion (weights).		
Vulnerability against floods (Ebert and Müller 2010):	E: none S: 6 components (building material, household size, age, females, green areas, building parts below street level) AC: 3 components (Unemployment rate, population without income, education level)	Chap. 7.1.5, page 144	
Climatic threat/ issue: Intensive precipitation and urban drainage floods			
Vulnerability Indicators for Bush Fires for the Sydney Coastal Councils Groups region to initiate a dialogue among researchers and stakeholders and a bottom-up assessment of local governments. (Preston et al. 2008)	E: 3 components (annual rainfall average and 90th percentile, change in rainfall extremes in 2030) S: 9 components (Land use, vegetation cover, drainage, water holding capacity, elevation, slope, population and road density, projected population growth) AC: 11 components (internet access, home loan, home ownership, household income, council expenses, >12yrs education, non-English speaker) Aggregation by summation of components values for each element, scoring, weighting based on expert values and summation of the elements values for vulnerability indicator.	Chap. 7.1.6, page 156	
Climatic threat/ issue: Sea level rise and storm surge-driven flooding			
Components influencing the vulnerability of European urban coastal areas to storm surge-driven flooding to raise awareness of the potential increase in flooding events (Harvey et al. 2009)	E: 2 components (sea level rise projection, change in height of storm surges); S: 4 components (flooded people, population density, elevation and slope, sea defences); AC: 2 components (GDP, education level); No aggregation suggested.	Chap. 7.1.7, page 159	The proposed indicators concentrate mainly on geomorphological and biophysical characteristics. Only few indicators consider socio-economic parameters, mainly coastal population density. Therefore most of them are of little use for urban areas. Also only few consider adaptive capacity, thus they the others are potential impact or pure sensitivity indicators. An interesting approach is used
Coastal sensitivity index (CSI) to assess and characterise susceptibility (Abuodha and Woodroffe 2010)	E: 3 components (Relative sea level rise, Mean wave height, Mean tidal range) S: 6 components (Rock type, Coastal slope, Geomorphology, Barrier type, Shoreline exposure, Shoreline change) Aggregation based on classification and ranking into one indicator.	Chap. 7.1.7, page 159	

Indicators for coastal vulnerability assessment at the regional scale to understand and manage the complexities of a specific study area (Torresan et al. 2008)	E: none S: 5 components (Administrative units, Location of rivers, Geomorphological characteristics, Wetland migratory potential, Coastal population density) AC: none Aggregation by classification and GIS overlay to derive homogeneous units.	Chap. 7.1.7, page 159	by Kleinosky et al. (2006) to calculate physical and social vulnerability independent, using different measures for current and future social vulnerability. To estimate future social vulnerability only scenarios for population distribution are used and no measure of adaptive capacity. The aggregation is either done with GIS overlay to derive homogeneous units or by simple multiplication of the classified components values without weighting.
Physical and social vulnerability to sea level rise and storm-surge flooding for local planners at Hampton Roads, a metropolitan region of 10 cities and six counties in southeastern Virginia, to understand how sea-level rise will increase the vulnerability of people and infrastructure to hurricane storm surge flooding over the next century (Kleinosky et al. 2006)	E: 1 components (maximum surge heights, elevation) S, AC: different approaches: 1. 3 components based on principal component analysis (current poverty, income, old age/disabilities) 2. current spatial distribution of critical features 3. projected spatial distribution of population density Combination of current and future physical (based on storm-surge model) and social vulnerability (based on different approaches). Aggregation by combination of statistical methods and combination of physical and social vulnerability.	Chap. 7.1.7, page 159	
The coastal vulnerability index (CVI) to identify areas at risk of erosion and/or extreme climatic events (Gornitz 1991)	E: 3 components (average swell, relative sea-level change tax, average tidal range) S: 3 components (geology resistance, erosion tax, coastal slope) Aggregation based on classification and ranking into one indicator.	Chap. 7.1.7, page 159	
Ecological and Socio-economic Vulnerability Indices for Andalusia (Andalusia, in preparation)	E: 2 components (height, distance to the shoreline with connectivity) S: 6 components (biocenotic diversity, natural values, residential uses, urban uses agricultural land uses, heritage) Aggregation still worked on	Chap. 7.1.7, page 159	
Vulnerability Indicators for Extreme Heat and Human Health for the Sydney Coastal Councils Groups region to initiate a dialogue among researchers and stakeholders and a bottom-up assessment of local governments. (Preston et al. 2008)	E: 1 component (Present relative storm surge) S: 11 components (Distance to coast, sensitive locations, elevation, slope, land cover, population density, road density, projected population growth to 2019, acid sulphate soils) AC: 12 components (internet access, home loan, ownership, household income, >12 yrs education, non-English speaker, council expenses) Aggregation by summation of components values for each element, scoring, weighting based on expert values and summation of the elements values for vulnerability indicator.	Chap. 7.1.7, page 159	

The evaluation of the existing indicators identified in this study (see Table 9) shows that vulnerability indicators

- including components of exposure, sensitivity and adaptive capacity exist for 6 issues; some indicators miss either exposure or adaptive capacity aspects, thus they are sensitivity indicators or potential impact indicators (as a function of impact and sensitivity).
- monitor either human health damage or infrastructure/economic damages. Only a few indicators cover both type of damage. Ecosystem service damage is only considered by very few indicators.
- are mainly based on past data for sensitivity and adaptive capacity components. Future data is only used in few indicators to estimate future exposure (climate projections) and very few indicators include components for future sensitivity (mainly population growth).
- focus mainly on city and municipality scale. Some indicators use data on building block scale, others data on national scale.
- are mostly developed based on a mixture of normative and inductive approaches. The selection of data is mainly based on literature review and data driven. Aggregation of the components is very diverse using normative approaches based on expert opinion or inductive (pragmatic) approaches using different statistical methods.

Table 9. Evaluation of the existing vulnerability indicators.

	Impact (I), potential impact (P - exposure and sensitivity only) and/or vulnerability (V) Indicators available	**Main type of damage considered**	**Temporal scale (past, current and future vulnerability)**	**Spatial scale (sub-city, city, national, European)**	**Approach for selecting – S and aggregating – A indicators (deductive, inductive, or normative)**
Higher temperatures, heat wave and health problems	I: yes P: yes V: yes (factors for adaptive capacity partly missing or based on local census data)	Human health damage	Mainly past (data constrains for projections of S and AC components)	city as well as national/ international scale	S: normative and inductive A: mainly inductive, partly normative
Decreased precipitation, water scarcity and drought	I: yes P: yes V: yes (very few)	Economic damages	Mainly past	National and international scale	S: mainly normative
Wild fires	I: yes P: yes V: yes (factors for adaptive capacity very general)	Economic damage	Mainly past	City (local) to larger urban zones (regional) scale	S: normative and inductive A: inductive, partly normative

Fluvial floods, flood claims and health effects of flooding	I: yes P: yes V: yes (factors for adaptive capacity partly missing or data difficult to achieve)	Human health and/or infra-structure (partly also ecosystem) damage	Mainly past (data constrains for projections of S and AC components)	Mainly sub-city to city scale (very detailed data necessary)	S: normative and inductive A: mainly inductive, partly normative
Intensive precipitation and urban drainage floods	I: no P: no V: yes (sensitivity and adaptive capacity with weak connection to the issues)	Economic damage	Mainly past, partly future (projections on population growth and climate)	City (local) to larger urban zones (regional) scale	S: normative and inductive A: inductive, partly normative
Sea level rise and storm surge-driven flooding	I: yes P: yes V: no (except a suggestion of Harvey et al. 2009)	Ecosystem and infrastructur e damage	Only past	Larger urban areas (regional), national to global scale	S: normative; A: mainly inductive (pragmatic)

The main shortcomings of the existing indicators are the missing theoretical background and transparency of their development: No convincing framework or methodology to select the components and aggregate the indicators could be identified, although some positive examples for a consistent methodological approach have been found (e.g. Preston et al. 2008, Kleinosky et al. 2006, Reid et al. 2009). The selection of the data was mostly based on literature review. Different components were selected for indicators with a similar purpose. Important aspects of vulnerability (e.g. side effects or adaptive capacity components) were not considered. The main cause of selecting a specific component was the data availability. The methods used for aggregation of the components vary considerable; it was also mostly data driven but partly expert opinions were used. An evaluation or validation of the proposed indices, e.g. in form of a plausibility check or sensitivity analysis of the components, is largely missing.

4.3 Vulnerability assessments outside Europe

It is important to look beyond Europe for good practice, in order to learn from similar experience in other developed countries which may be looking at similar climatic issues and dealing with similar problems. Below are three relevant examples of future vulnerability to climate change assessments of cities outside Europe.

Indicators and monitoring: New York, USA

The ambition of the City of New York's Climate Change Adaptation Task Force is to develop flexible adaptation pathways for critical infrastructure within the City region (Jacob et al. 2010). These pathways are based on a number of practical and programmatic objectives that need to be monitored and measured through indicators. The ambition is that the indicators will enable policy-makers to time their interventions and identify 'course corrections' in adaptation policy. The framework adopted by the Task Force covers a number of indicator types to address the requirements of the end-users:

- **Physical climate change exposure indicators**. In particular to monitor changes in relevant climatic variables (related to temperature, precipitation and sea-level rise which in turn can be linked to particular climate hazards) in trends relative to forecast or projected values;

- **Impact and sensitivity indicators**. Although less consistently collected and harder to find, these indicators would be pulled from existing monitoring within the city by different agencies (e.g. for precipitation, one suitable impact or risk is reservoir capacity. This is currently tracked);

- **Adaptation indicators for measures and their effectiveness**. To demonstrate that adaptation is taking place (process-based) and whether it is effective (outcome-based);

- **New research findings and information**. Tracking advances in the theory of climate change, observations, projections, impacts modeling and the effectiveness of adaptation interventions.

Important lessons from this work for the EEA include the institutional process and requirements for data capture, translation and communication. For pragmatic reasons, many of the proposed indicators are already collected by a range of different Government (Federal and State) Agencies. An important task, therefore, is to provide an institution that can collate and process the data, e.g. to standardize and format data sets and impose quality controls. An important conclusion that maybe overlooked is that "the greater the number and complexity of indicators…the greater the need for centralized coordination and data storage" (Jacob et al. 2010, p.136). The full New York City Panel on Climate Change report outlines the risk-based approach adopted by the City. As discussed in section 4.4, the issue about monitoring changes in research is also particularly relevant for the EEA as large volumes of material are being developed by EU funded research programs and member state initiatives.

Dealing with multiple critical issues: Sydney, Australia

Preston et al. (2008) used the IPCC definition in their work on mapping climate change vulnerability in the Sydney Coastal Councils Region (SCCG), but they also spent time on the conceptual development and defined the IPCC terms further making them applicable for the region, and for Australia, and used this to build conceptual models and indicators for vulnerability to:

- extreme heat and health effects;
- sea-level rise and coastal management;
- extreme rainfall and storm water management;
- bushfire;
- and effects on ecosystems and natural resources.

These data were combined in a GIS system to produce a map of the relative vulnerability of the SCCG region.

Based on this system, the authors selected their components and aggregated them. Importantly they used a combination of stakeholder and expert opinions, utilising local knowledge to improve the assessment. This work also involved extensive discussion of the purpose and limitations of the vulnerability indicators. Thus, they ultimately propose a methodological approach and framework to develop vulnerability indicators for different threats to urban regions. The Preston et al. (2008) report is pragmatic and set outs to provide solutions but nevertheless, the work faces the same problems and gaps identified for other vulnerability assessments by indicator (see section 4.2). This approach is looking at impacts, vulnerability and adaptation across different climatic threats, building on a similar framework used in this scoping study. The EEA could transfer this conceptual approach and develop it further.

Semi-qualitative approach for Buenos Aires, Delhi, Lagos, and New York

As an alternatively to a quantitative vulnerability assessment using indicators, the semi-qualitative approach of Mehrotra et al. (2009) could be considered. They estimate and compare overall vulnerability of very different cities based on a description of their exposure (they use the term hazard), sensitivity (they use the term vulnerability) and adaptive capacity, which are assessed based on common criteria evaluated by city experts (see **Table 10. Elements of vulnerability and its components (Mehrotra et al. 2009).**Table 10).

Table 10. Elements of vulnerability and its components (Mehrotra et al. 2009).

Exposure	Sensitivity	Adaptive Capacity
1. Temperature (observed trend and projections for 2050s) 2. Precipitation (observed trend and projections for 2050s) 3. Sea-level (observed trend and projections for 2050s) 4. Tropical cyclone 5. Drought 6. Heat waves	1. Population 2. Density 3. Percent slum population 4. Percent of urban area susceptible to flooding 5. City % of national GDP	**Institutions and Governance** 1. Urban governance (corruption index ranking for city) 2. City leadership is willing to address climate change **Information and Resources** 3. Comprehensive analysis of climate risks for the city 4. Administrative unit assigned to address climate change 5. Balance between adaptation and mitigation

Again, the EEA could undertake a similar process with city representatives from the EEA country cities to discuss and agree a set of semi-qualitative descriptors, and use this in combination with expert opinion to decide on the datasets to be used and the weighting give to each element.

4.4 Gaps and further information available: now and next year

It is clear from section 3.4 and 5.2 that there are constraints on our ability to develop vulnerability indicators because of gaps in our knowledge and data availability. This section provides an overview of the knowledge gaps that limit the development of vulnerability indicators. However, there are also many ongoing initiatives and projects that will help 'plug' some of the more general knowledge gaps and help improve the existing threat specific vulnerability indicators identified in Table 8. Drawing on a previous study, this section identifies four types of knowledge and data gaps relevant for this scoping study that are present at the European scale (high-level gaps) down to the level of particular issues, indicators or individual cities, see Figure 5 for a schematic. This section provides an indicative assessment of the extent to which these gaps at different scales could be addressed by ongoing projects and initiatives.

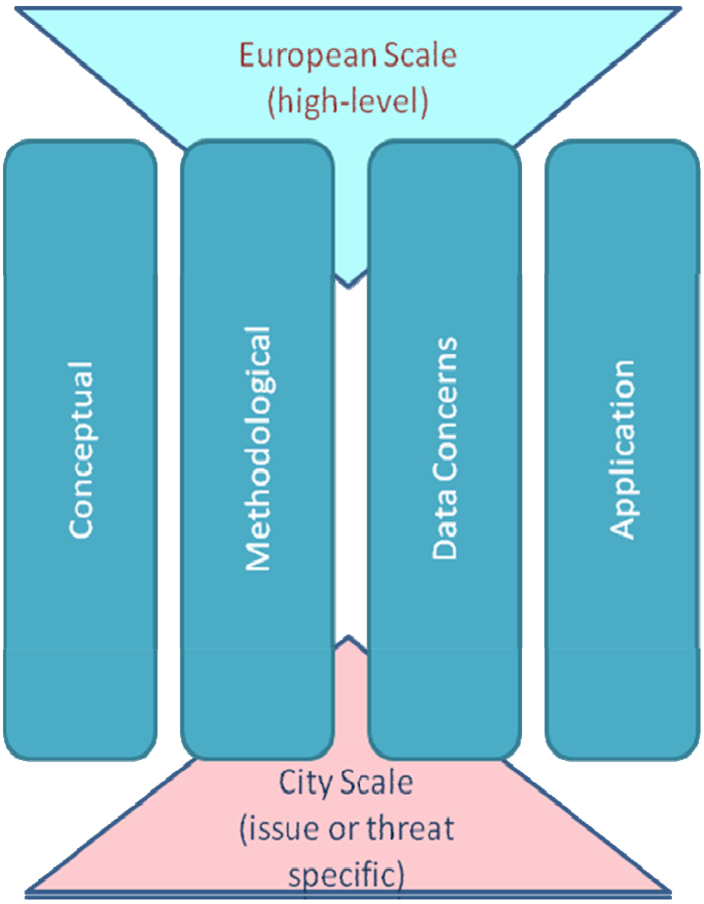

Figure 5. Knowledge gaps and spatial scales for the development of climate change vulnerability indicators.

High level gaps and high level initiatives

The Impact Assessment to the European Commission's White Paper on Adaptation (EC 2009a) identifies a number of high-level actions needed to improve the knowledge base on climate change impacts and adaptive capacity to enable adaptation across Europe. This includes the need for "further improvement of the quality and coverage of the analysis of climate change impacts for major sectors" (EC 2009a, p.125). An additional key challenge at the European level is how all the disparate sources of data on climate change impacts, vulnerability and adaptation can be managed efficiently and effectively and made available for stakeholders. This is a key ambition of the European Climate Change Impacts, Vulnerability and Adaptation Clearinghouse that is currently under development. Although these problems are generic for furthering adaptation across Europe, they are also relevant for the development of vulnerability indicators for urban areas. A more specific set of knowledge and data gaps relevant for developing climate change vulnerability indicators to support future EU spatial development policy were identified by a previous study (Harvey et al. 2009) and included:

- **Conceptual gaps**: some aspects of the broad conceptual framework for European vulnerability indicators are still undecided and the conceptual links between vulnerability indicators and other tools and frameworks that are available for European policy appraisal and adaptation assessment. Some gaps can be filled through review and synthesis of outcomes of ongoing research projects, but in some cases, primary research will be needed;

- **Methodological questions**: there are a number of gaps in knowledge about how to select components of vulnerability for any given climate issue, as well as about whether and how best to aggregate indicators developed for very different issues. In some cases, primary research is warranted. Since the definition of vulnerability indicators is based on normative decisions, the opinions of experts and stakeholders need to be involved;

- **Data concerns:** further exploration of the requirements relating to the collection and publication of vulnerability datasets is needed, particularly in relation to quality assurance, and the potential for security, commercial or investment consequences of publishing European-wide vulnerability data. The availability of data is an important constraint on the development of any indicator. At the European level there are well-documented problems with data coverage, quality and type; this was a significant limiting factor in the development of the EEAs' set of impact-based indicators (EEA 2008). See below for a discussion of data availability and quality;

- **Application gaps**: questions surrounding the way in which vulnerability indicators would be used to support adaptation, including gaps in policy formulation relating to the purposes for which vulnerability data would be used.

At the European level there are a number of high-level initiatives that will eventually contribute to help address some of these gaps. For example, the White Paper (EC 2009b) identifies a number of actions that are particularly relevant in this context and aim at improving the knowledge base on climate change impacts and adaptive capacity such as the "development of consistent, comprehensive and regularly updated climate change and socio-economic scenarios" and the development of a "structured information data set to better understand the territorial and sectoral distribution of vulnerability to climate change impacts" (EC 2009b, p.124). This work will be important for the development of urban vulnerability indicators but the timelines and process for development of such work currently remains unclear.

There are also a wide number of ongoing projects and initiatives that will help with the development of policy-relevant indicators to inform funding priorities across the EU in the future. An important distinction to make is between projects and initiatives that will directly supply relevant data (for example, for specific variables) and those that will help develop conceptual and / or methodological approaches to vulnerability more generally (for example, methods to aggregate components or leading to an improved understanding of the system in question).

Over 80 projects were identified by the project team that could potential be relevant for the future study on urban vulnerability indicators. The projects were analysed to see which of them planned to address any of the four identified types of gaps that hinder the development of vulnerability indicators per issue (Table 11). The results provide an indication of the focus of recent and ongoing work that will help inform a more detailed analysis for particular indicators within the context of a more comprehensive report and indicator development.

Within the range of projects surveyed, certain projects are key for future work as the expected outputs are directly relevant for the development of vulnerability indicators (e.g. EVDAB, ARCADIA, KIBEX, ECOCITIES, GRaBS, SCORCHIO). Some projects (e.g. CLIMSAVE, MEDIATION, MOVE, ENSURE, CLISP, ESPON Climate Change) aim at improving the general methodology of selecting and aggregating vulnerability components.

This assessment is not comprehensive – but illustrates a number of important points:

- The majority of projects focuses on conceptual and methodological issues and therefore is most appropriate to address those particular types of gaps. As stressed in section 4.1 it is important to be precise when specifying the parameters for vulnerability assessment and therefore there are likely to be limits in the transferability of these projects to the specific requirements of the EEA in this context;

- There are fewer projects concerned with addressing data or application issues. This perhaps reflects the 'state of play' of indicator development within Europe;

- Table 11 illustrates the challenge of knowing a) what projects are actually going on within EEA member countries, b) understanding how they are relevant to this (or any) particular project and c) enabling access to relevant outputs;

- In terms of data, many of the same sources will have been used across projects. Annex 7.2 describes several key initiatives and data sources.

Data quality

A further point concerning gaps and further information is the issue of data quality. There is an important distinction between 'true' datasets (i.e., those that are quality controlled, publicly available, maintained and standardized) and the results of studies or projects. A hierarchy of data is available for European vulnerability indicators such as that held by EUROSTAT to the output from modelling studies and observations. A key source of information will be from projects funded through the 7th Framework and INTERREG programmes such as those in Table 11. However, whilst it may be appropriate for indicators to draw on existing information such as projects and reviewed papers, this leads to trade-offs, for example in the range of emission scenarios used, the robustness and continuity of data.

Table 11. Examples of impacts, vulnerability and adaptation projects addressing gaps for developing vulnerability indicators.

Issues	**Knowledge (conceptual) gaps:** *projects which aim to analyze the cause and effect chain of impacts and vulnerabilities either qualitatively or quantitatively*	**Methodological questions:** *projects which aim to address gaps in indicator methodologies*	**Data concerns and gaps:** *projects which aim to address gaps in specific system or group vulnerability data*	**Application gaps:** *projects which actually apply vulnerability indicators*
1. Higher temperatures, heat wave and health problems	ADAM , ASTRA, ASSCUE, PLAN, CLIMSAVE, ARCADIA, CREW, CLISP, DELTARES / UNESCO-IHE, MOVE, KIBEX, SCORCHIO, C-Change, ECOCITIES, ESPON Hazards and Climate Change	ADAM , GRaBS, ASSCUE, CREW, CLIMSAVE, ARCADIA, SCORCHIO, MOVE, CLISP, ECOCITIES, EVDAB , ESPON Climate Change	ASSCUE, CLIMSAVE, ARCADIA, MOVE, CLISP, ECOCITIES, ESPON Climate Change	ASSCUE, ARCADIA, CLIMSAVE, SCORCHIO, KIBEX, MOVE, CLISP, ECOCITIES, EVDAB, ESPON Climate Change
2. Decreased precipitation, water scarcity and drought	ASTRA, ADAM, AlpWaterScarce, ASSCUE, CLIMSAVE, CREW, DELTARES / UNESCO-IHE, KIBEX, SCORCHIO, MOVE, CLISP, MEDIATION, ESPON Hazards and Climate Change	GRaBS, ADAM, ASSCUE, CLIMSAVE,CREW, SCORCHIO, MOVE, CLISP, MEDIATION, ESPON Climate Change	ASSCUE, CLIMSAVE, DELTARES / UNESCO-IHE, MOVE, CLISP, MEDIATION, ESPON Climate Change	ASSCUE, CLIMSAVE, SCORCHIO, MOVE, CLISP, ESPON Climate Change
3. Wildfires	ASTRA, MOVE, CLISP, ESPON Hazards	MOVE, CLISP, EVDAB	MOVE, CLISP	MOVE, CLISP, EVDAB
4. Heavy precipitation and fluvial floods	ADAM, ASTRA, ASSCUE, ACQWA, DELTARES / UNESCO-IHE, KIBEX, CLIMSAVE, CREW, ARCADIA, CLIMATECOST, KLARA-Net Phase I and Phase II, INDIKATOREN, MOVE, CLISP, MEDIATION, ECOCITIES, ESPON Hazards and Climate Change	GRaBS, ASSCUE, INDIKATOREN, DELTARES / UNESCO-IHE, CLIMSAVE, ARCADIA, MOVE, CLISP, ECOCITIES, MEDIATION, EVDAB, ESPON Climate Change	ASSCUE, CLIMSAVE, ARCADIA, CLIMATECOST, MOVE, CLISP, ECOCITIES, MEDIATION, ESPON Climate Change	ASSCUE, ARCADIA, INDIKATOREN, KIBEX, CLIMSAVE, MOVE, CLISP, ECOCITIES, EVDAB, ESPON Climate Change
5. Intensive precipitation and urban drainage floods	ADAM, ASTRA, ASSCUE, INDIKATOREN, PLAN, ACQWA, CLIMATECOST, CLIMSAVE, ARCADIA, PREPARED, CREW DELTARES / UNESCO-IHE, KIBEX, MOVE	GRaBS, ASSCUE, INDIKATOREN, CLIMSAVE, ARCADIA, CREW, MOVE	ASSCUE, CLIMATECOST, CLIMSAVE, ARCADIA, DELTARES / UNESCO-IHE, MOVE, PREPARED	ASSCUE, INDIKATOREN, CLIMSAVE, MOVE

6. Sea level rise and storm surge-driven flooding	ASTRA, ADAM, ASSCUE, CLIMATECOST, CLIMSAVE, DELTARES / UNESCO-IHE, MEDIATION, ESPON Hazards, ESPON Climate Change	ADAM, ASSCUE, CLIMSAVE, MEDIATION, ESPON Climate Change	ASSCUE, CLIMSAVE, DELTARES / UNESCO-IHE, MEDIATION, ESPON Climate Change	ASSCUE, CLIMSAVE, ESPON Climate Change
7. Saltwater intrusion	ESPON Climate Change	ESPON Climate Change	ESPON Climate Change	ESPON Climate Change
8. Wind storms	ASTRA, KLARA-Net Phase I and Phase II, ESPON Hazards			
9. Mass movements and erosion	ACQWA, Paramount, MOVE, CLISP, ESPON Hazards	MOVE, CLISP	Paramount, MOVE, CLISP	MOVE, CLISP
10. Vector–borne and other diseases	KLARA-Net Phase I and Phase II			

ACQWA – Assessment of climatic change and impacts on the quantity and quality of water
ADAM – Adaptation and Mitigation Strategies. Supporting European Climate Policy
AlpWaterScarce – Water Management Strategies against Water Scarcity in the Alps
ARCADIA – Adaptation and Resilience in Cities: Analysis and Decision making using Integrated Assessment
ASSCUE – Adaptation Strategies for Climate Change in the Urban Environment
ASTRA – Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region
C-Change – Changing Climate, Changing Lives
CLIMATECOST – Full cost of climate change
CLIMSAVE – Climate change integrated assessment methodology for cross-sectoral adaptation and vulnerability in Europe
CLISP – Climate Change Adaptation by Spatial Planning in the Alpine Space
CREW – Community Resilience to Extreme Weather
DELTARES / UNESCO-IHE – Building the Netherlands Climate Proof
ECOCITIES initiative – The Bruntwood Initiative for sustainable cities at the University of Manchester
ESPON Hazards Project - The spatial effects and management of natural and technological hazards in general and in relation to climate change
ESPON Climate Change Project - Climate Change and Territorial Effects on Regions and Local Economies in Europe
EVDAB – European Database of Vulnerabilities for Urban Areas
GRaBS – Green and Blue Space Adaptation for Urban Areas and Eco Towns
INDIKATOREN – Vulnerability of Urban Areas to Floods: Indicators for the assessment of vulnerability and coping capacity with respect to urban flooding
KIBEX – Critical Infrastructure, and civil protection in the context of climate change related extreme events in Germany
KLARA-Net Phase I and Phase II – Network for climate adaptation in the region around Starkenburg
MEDIATION – Methodology for Effective Decision-making on Impacts and Adaptation
MOVE – Methods for the Improvement of Vulnerability Assessment in Europe
Paramount - Improved Accessibility: Reliability and security of Alpine transport infrastructure related to mountainous hazards in a changing climate
PLAN – Responding to Climate Change: The Potentials of and Limits to Adaptation in Norway
PREPARED – Enabling Change on "Adaptation of Water Supply and Sanitation Systems to cope with Climate Change"
SCORCHIO – Sustainable Cities: Options for Responding to Climate Change Impacts and Outcomes

To summarise: section 4.3 and 4.4 highlights that there are a wide number of ongoing projects and initiatives that will help with the development of policy-relevant indicators to inform funding priorities across the EU in the future.

However, much of our current and future information comes from quite specific studies of particular threats to particular groups at a particular time. There are challenges in trying to up-scale this information and the particular value of such material (e.g. the specific contextual components that influence vulnerability) are likely to be lost when applied with a coarser granularity across a wider area.

There is a continuing challenge in drawing together the breadth and depth of relevant material at the European level. While this represents an excellent opportunity for the full study planned in 2011 to become a benchmark of urban vulnerability to climate change, it also presents well recognised challenges of synthesis. However, the ambition is that scoping study will lay the necessary foundations for a more comprehensive analysis of the issues.

There is a danger that indicators can become solely supply driven – in other words developed in a particular form because of the constraints of available data. Ideally a stronger and clearer policy demand would help inform more accurately a gap analysis and future research agenda.

5 Testing vulnerability indicators for cities

5.1 Introduction to mapping (urban) vulnerability

Objective of chapter 5 is to test various different existing indicators (for specific hazards) and to create exemplary maps visualizing the spatial distribution of certain indicator values. An additional output will be to point out major potentials and constraints of existing indicators when applied and transferred into practice.

The communication of the results of indicator assessment is a crucial part of any study. Mapping the results is a common communication methodology. However, there are qualitative and quantitative, spatially explicit and social class related aspects of vulnerability. Some can be visualized through maps, figures and profiles, some need to be explained by text. Moreover, due to the complexity of vulnerability often detailed explanations are necessary for clarifying the results. The degree of participation of stakeholders and end-users in the process of the vulnerability development may significantly enhance the validity and acceptance of the results.

O'Brien et al. (2004, p. 311) describes two general problems of mapping vulnerability which also apply to urban vulnerabilities:

1. "Mapping vulnerability at a detailed city district level may lead to a false sense of precision. Abrupt differences in vulnerability across district boundaries might be more realistically represented as fuzzy transitions. Similarly, differences between single vulnerability groups and within city districts are not captured in the vulnerability maps."

2. "Uncertainties associated with regionally downscaled climate scenarios (or scenarios of trade liberalization) are not explicitly represented in the maps. Incorporation of the uncertainties associated with different climate scenarios might be addressed through application of a range of different regionally downscaled models."

Results of vulnerability assessments can easily be altered or 'manipulated' for example by changing the mode how individual indicator components are composed. Another possibility to influence the perception of vulnerability estimates is the determination of a legend to map results that is the choice of thresholds, colours and symbols for visualisation. It is therefore important to communicate details and the rational for decisions about aggregation and demonstration procedures.

Within this chapter some indicators were computed for a number of urban areas. Starting point for the selection of indicators were the tables describing the indicators in annex 7.1. Due to limited time and resources the final choice of indicators and cities on which these indicators have then been tested was mainly guided by feasibility, that is data availability, time required for data processing, personal contact to authors but also communicated interest of city administration.

As a result the following hazards and indicators were selected for a test at sub-city level:

- Heat wave
  - Cities: Birmingham and Bolzano
  - Indicator : Regional vulnerability indicator (RVI) (Kropp et al. 2009, see annex 7.1.2)
- Flood
  - Cities: Salzburg and Hamburg
  - Indicators: Social susceptibility index (SSI) (Fekete 2009, see annex 7.1.5) & Spatial vulnerability units (SVU) (Kienberger et al. 2009, see annex 7.1.5)

Though the main criteria for indicators selection was feasibility the exercise suffered significantly from the lack of access to details about indicator composition methodologies as well as from the availability of and the timely access to the underlying data sets.

5.2 Regional Vulnerability Indicator (RVI) for heat wave

Kropp (et al. 2009) developed their heat wave indicator within the scope of a climate change vulnerability study for North Rhine Westphalia. This indicator does not include any components that describe the adaptive capacity of the region. Hence in the IPCC understanding of vulnerability the indicator does not assess the vulnerability but rather the potential impact of heat waves (as combination of exposure and sensitivity). For this composite indicator the following variables were aggregated:

- Exposure components:
  - Number of heat days (for the years 2020, 2050 and 2080)
- Sensitivity components:
  - Impervious area (%)
  - Population density (people/km²)
  - Population > 65 yrs

A composite indicator combines a number of components measured in different units into a single number with a common unit. Kropp et al. (2009) uses fuzzy logic techniques for this combination in order to account for a quantification of uncertainties. These techniques allow for gradual instead of binary allocation of variable values to classes. For example in an area where a population density of 500 persons/km² is classified as low and a density of 1000 persons/km² is classified as high, the allocation of membership values to the class ‘high population density’ is ‘0’ for the former value 500 persons/km² and ‘1’ for the latter value of 1000 persons/km². The values in between these two thresholds are then allocated to the class ‘high population density’ according to a linear function that could for example result in the number ‘0.5’ for the value 750 EW/km2.

The various class allocation values are then combined by using the fuzzy operator ‘or’ and considering only the lowest of all input values, with the exception of the combination of ”Urban Heat Island Potential” and “population over 65 years”, for which the compensative ‘or’ operator is applied, that allows for the integration of both input variables. The decision tree developed by Kropp et al. (2009) for logical aggregation of variables into the final indicator value is shown in Figure 6. The results of the application of the RVI (heat) for Birmingham and Bozen are shown in Figure 7 and 8.

Further details about the method applied by Kropp et al. (2009) in the test case of Northrhine Westfalia were not available. The RVI indicator has been adapted for this test study in order to improve the spatial resolution of the exposure data based on the indicator 'Number of Heatwaves'. Therefore remotely sensed satellite data, namely values of Land Surface Temperature (LST) derived from Band 6 of LANDSAT TM scenes with a pixel size of 120 m have been integrated into the exposure data layer. These LST values have been atmosphere corrected and calibrated by means of MODIS LST scenes (Sobrino et al. 2004). They were used for disaggregating the climate scenario outputs that represent the base for the exposure values and are only available at a spatial resolution of 25 km pixel size. For this study the Global model 'HadCM3Q0' and the Regional Model 'HadCM3Q0' was applied. The data represent results from the Ensemble Project and have been provided by the Met Office Hadley Center (www.ensemblesrt3.dmi.dk). The time spans considered are:

- 2010 -2040 for calculating the values of the year 2020
- 2040 - 2070 for calculating the values of the year 2050
- 2070 – 2100 for calculating the values of the year 2080.

LST is only an error prone indicator for air temperature that is strongly influenced by land cover (or surface material such as varieties in roofing). Nevertheless it has the potential to distinguish areas that are more or less prone to increased urban heat island effects.

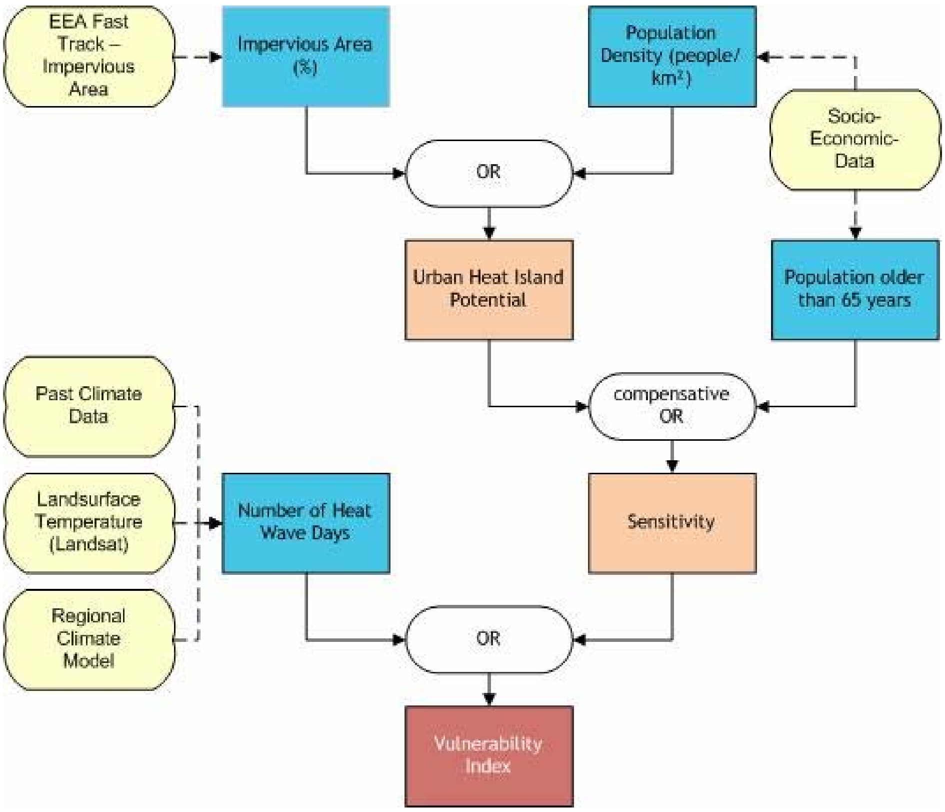

Figure 6. Flow chart visualising the composition of individual variables for the Regional Vulnerability Indicator (RVI heat).

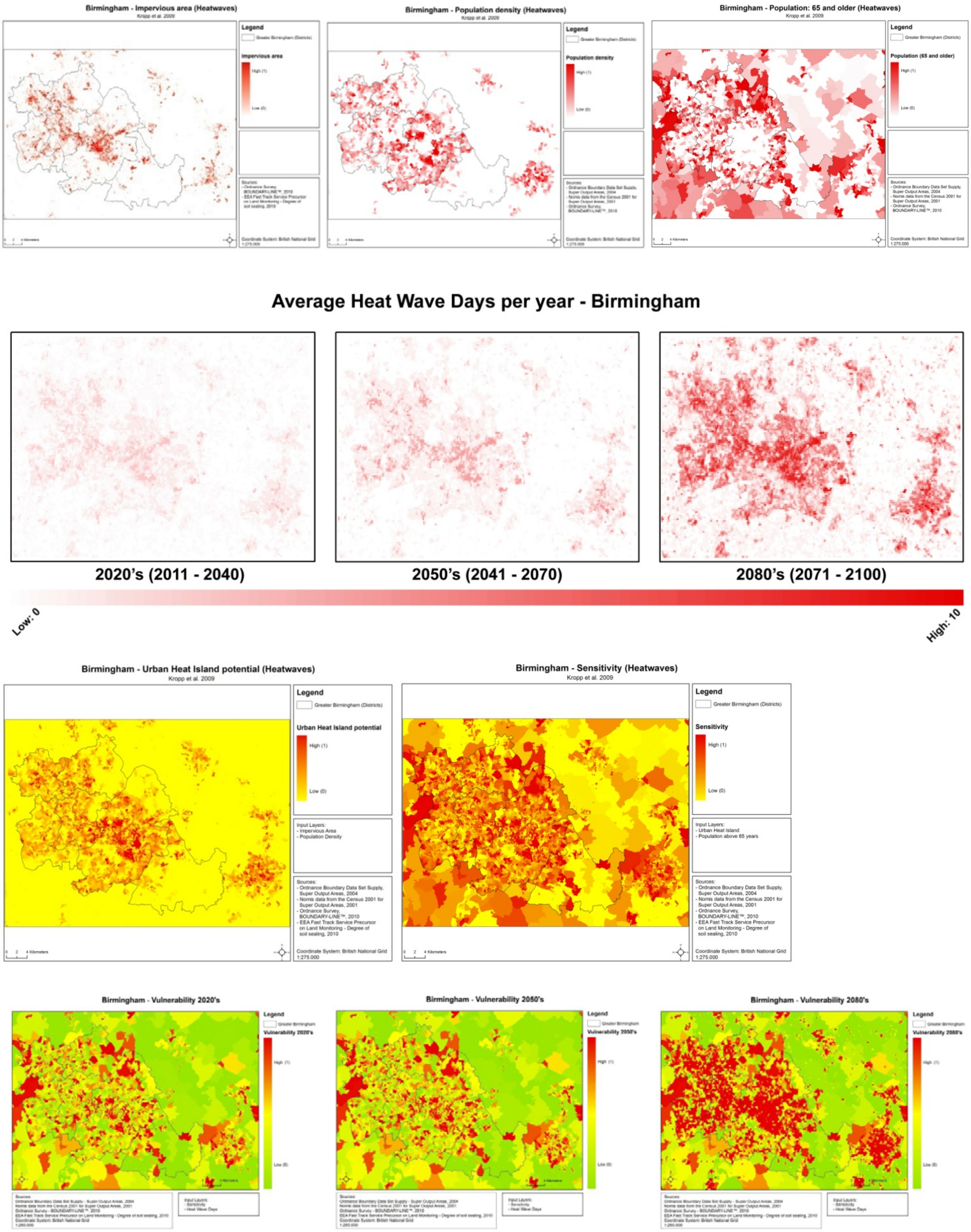

Figure 7. The results of the RVI (heat) for the city of Birmingham

(Data sources: Global model 'HadCM3Q0' and Regional Model 'HadCM3Q0' from Ensemble Project, Met Office Hadley Center. www.ensemblesrt3.dmi.dk, Census data 2001, Office for National Statistic UK (2010) http://www.ons.gov.uk/census/index.html, Lower Super Output Areas for England, ONS Geography (2004), Boundary-Line, Ordnance Survey. https://www.ordnancesurvey.co.uk/opendatadownload/products.html)

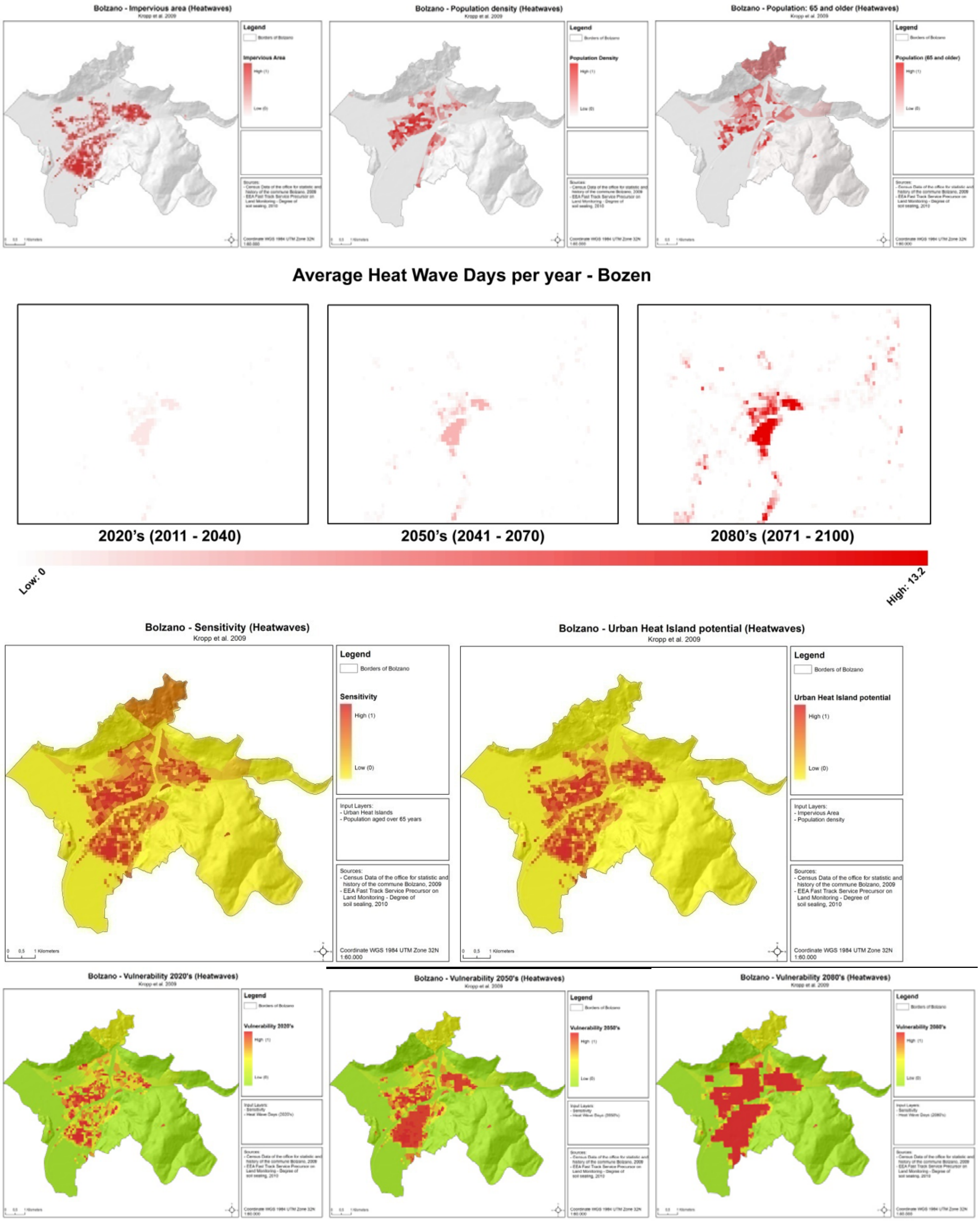

Figure 8. The results of the RVI (heat) for the city of Bolzano.

(Data sources: Global model 'HadCM3Q0' and Regional Model 'HadCM3Q0' from Ensemble Project, Met Office Hadley Center. www.ensemblesrt3.dmi.dk, City districts, statistical office commune Bolzano (2009), Census Data 2009, statistical office commune Bolzano (2009), LST –Landsat 5 and 7, NASA http://earthexplorer.usgs.gov/, MODIS, NASA. http://ladsweb.nascom.nasa.gov/)

5.3 Social Susceptibility Index (SSI) for fluvial floods

Fekete (2009) has composed his index in the context of river floods in Germany. Originally his approach was developed for the major river channels in Germany and was carried out at county level. His focus is set on social and economic characteristics of populations which can be combined with the number of populations potentially exposed to floods and an indicator for infrastructure density. Here only the socio-economic part of Fekete's indicator has been tested since the data for the exposure component was not available in time and the rationale for the aggregation methodology chosen to combine the SSI (floods) with the exposure components is only vaguely described by Fekete. Thus, following the IPCC terminology the SSI (floods) assesses aspects of sensitivity and - in a very generic sense – of adaptive capacity components and not the exposure part of vulnerability. Therefore the mapped results of the SSI are overlaid for this study with a grey polygon showing areas potentially exposed to floods.

Fekete (2009) applied factor analysis and binary logistic regression analysis in order to identify and group variables most strongly correlated with the impact of river floods. His work is based on (1) a number of available socio-economic datasets and (2) data on latest extreme flood events in Germany (stemming from a survey conducted by the German Research Centre for Geosciences (GFZ) and the Deutsche Rückversicherung AG). The final list of variables clustered by Fekete into the factors 'region', 'fragility' and 'socio-economic conditions' are shown below.

- Region:
  - Population per settlement area (-)
  - One and two family homes (+)
  - Rural population *(One and two family homes)* (+)
  - *Small apartments* (-)
  - Living space per person (+)
- Fragility
  - Residents from age 30 to 50 (-)
  - Residents age 65 and older (+)
  - Unemployment (+)
- Socio-economic conditions
  - One and two family homes (-)
  - Unemployment (+)
  - Living space per person (-)
  - Only elementary education (+)

Those variables finally integrated into the SSI floods are written in italics. For this test study that concentrated on urban areas we replaced the variable 'Rural population' with data from the variable '*One and two family homes'.* Underlying datasets were harmonized by Fekete (2009) prior to the factor analysis and standardized afterwards resulting in values between 0 and 1 for each variable. Each variable exhibits a positive or negative sign derived from the result of the factor analysis. The variables are summed up to one value per factor, first building the average of variables with the same sign. The final SSI is then the simple sum of the factor values:

- $SSI = Region + Fragility + Socio - Economic\ Conditions$

Figure 9 visualises the logic of variable and factor aggregation for the SSI (floods). The results of the application of the SSI (floods) for Hamburg and Salzburg are shown in Figure 10 and 11.

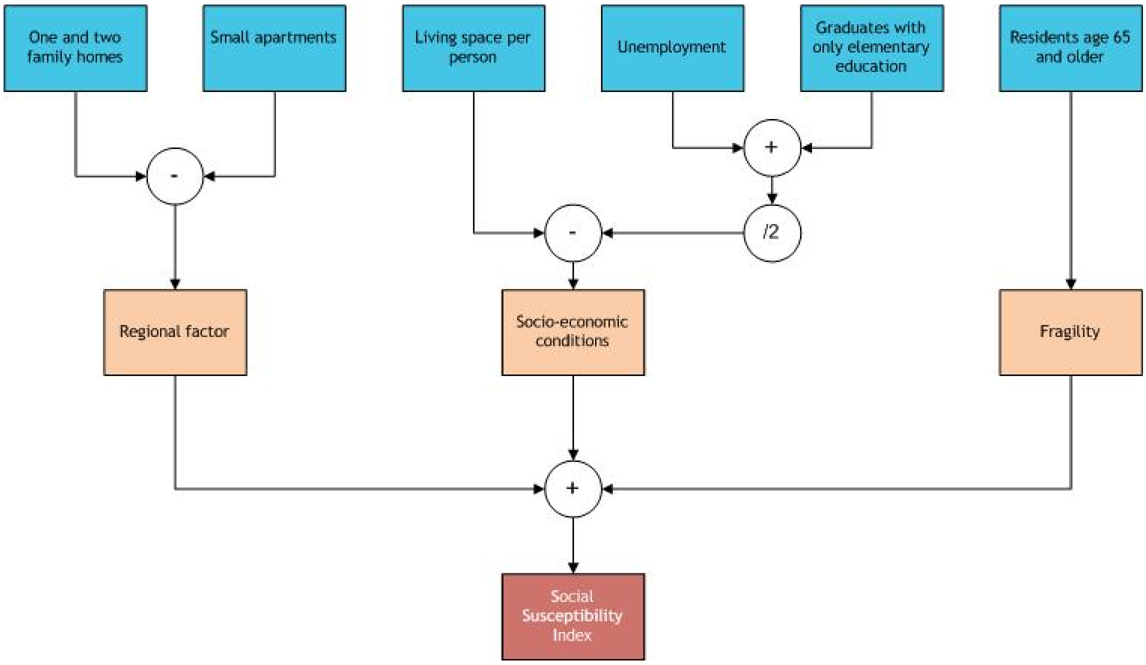

Figure 9. Flow chart visualising the aggregation of variables and factors for the SSI (floods).

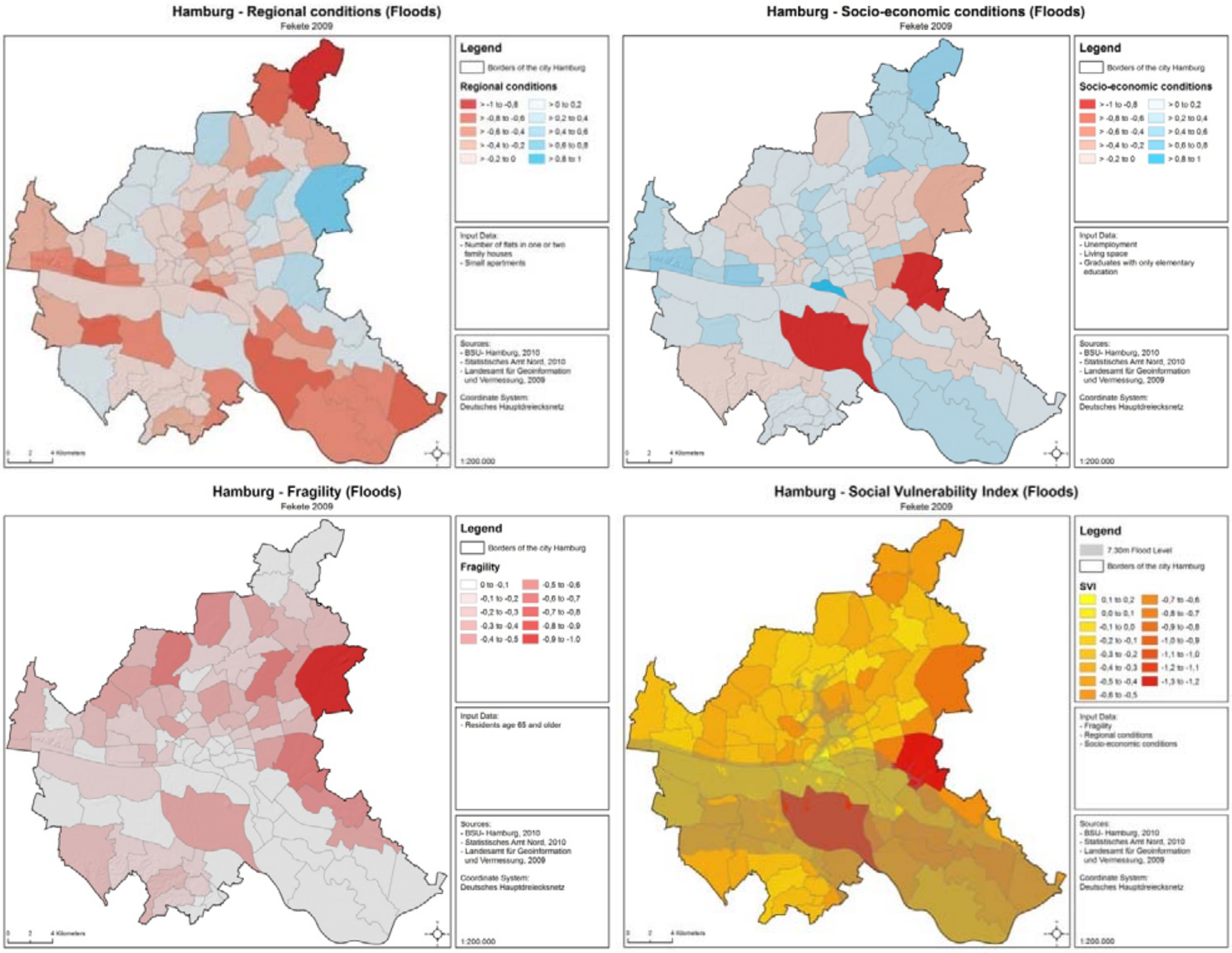

Figure 10. The results of the SSI (floods) for the city of Hamburg.

(Data sources: Census data 2010 - Statistik Nord (BSU), Digital Elevation Model - Landesbetrieb für Geoinformation und Vermessung (BSU), District Borders - Landesbetrieb für Geoinformation und Vermessung (BSU), Statistics of Graduates - Statistik Nord (BSU), ALKIS - Landesbetrieb für Geoinformation und Vermessung (BSU), CORINE Land Cover 2006 – EEA, IUCN and UNEP-WCMC (2010), The World Database on Protected Areas (WDPA): Annual Release [On-line]. Cambridge, UK: UNEP-WCMC. Available at: www.wdpa.org [Accessed 24.11.2010]).

Figure 11. The results of the SSI (floods) for the city of Salzburg.

(Data sources: Salzburg geographic information system, SaGIS, Census data - Bundesanstalt Statistik Österreich, http://www.statistik.at/web_de/statistiken/regionales/regionale_gliederungen/raster_mgi_lambert/index.html, Digital Elevation Model, Z_GIS – Zentrum für Geoinformatik/Land Salzburg ,Flood areas, Z_GIS – Zentrum für Geoinformatik/Land Salzburg, Kienberger et al. 2009)

5.4 Spatial Vulnerability Units (SVU) for fluvial floods

The indicator developed by Kienberger et al. (2009) attempts to describe aspects of vulnerability in the context of climate change, targeting the hazard “flood”. Again, in the IPCC understanding of vulnerability this indicator does not assess vulnerability since exposure components are missing. Therefore the mapped results of the SVU are overlaid for this study with a grey polygon showing areas potentially exposed to floods. The methodology has originally been applied in the river Salzach catchment in Austria.

Variables of relevance for the description of spatial differences in susceptibility to river floods have been identified with expert and stakeholder knowledge out of a large number of datasets ranging from infrastructure, administrative boundaries to socio-economic and demographic topics. Within the scope of a scoring exercise these variables were then clustered into the factors ‘susceptibility’, ‘resilience’ and ‘social capacity’ and individual weighting values at variable and at factor level were determined for aggregation.

The values at the sub-indicator levels 'sensitivity' and 'adaptive capacity' is then calculated as the sum of the normalized and weighted value for each variable and its respective factor level in each raster cell.

The list below shows the identified variables, their weighting factors and their allocation to the factors 'sensitivity' and 'adaptive capacity'

- **Sensitivity**
    - Susceptibility – Housing/Buildings [0.158]
    - Susceptibility – Infrastructure [0.105]
    - Susceptibility – Assets [0.125]
    - Susceptibility – "Silent" Land Cover [0.053]
    - Susceptibility – Population: age distribution [0.073]
    - Susceptibility – Population: means of subsistence [0.043]

- **Adaptive Capacity**
    - Resilience – Workforce in economy sectors [0.065]
    - Resilience – Size of companies/workplaces [0.040]
    - Resilience – Ecosystem integrity [0.105]
    - Resilience – Access [0.050]
    - Social Capacity – Early Warning [0.125]
    - Social Capacity – Origin of population [0.015]
    - Social Capacity – Education [0.045]

The results at the sub-indicator levels the factors 'sensitivity' and 'adaptive capacity' are then visualized as SVUs by carrying out homogenization techniques that allow to cluster pixel in spatial vicinity that exhibit similar values. The concept of composition is shown in Figure 12 (flow chart SVU (flood) indicator).

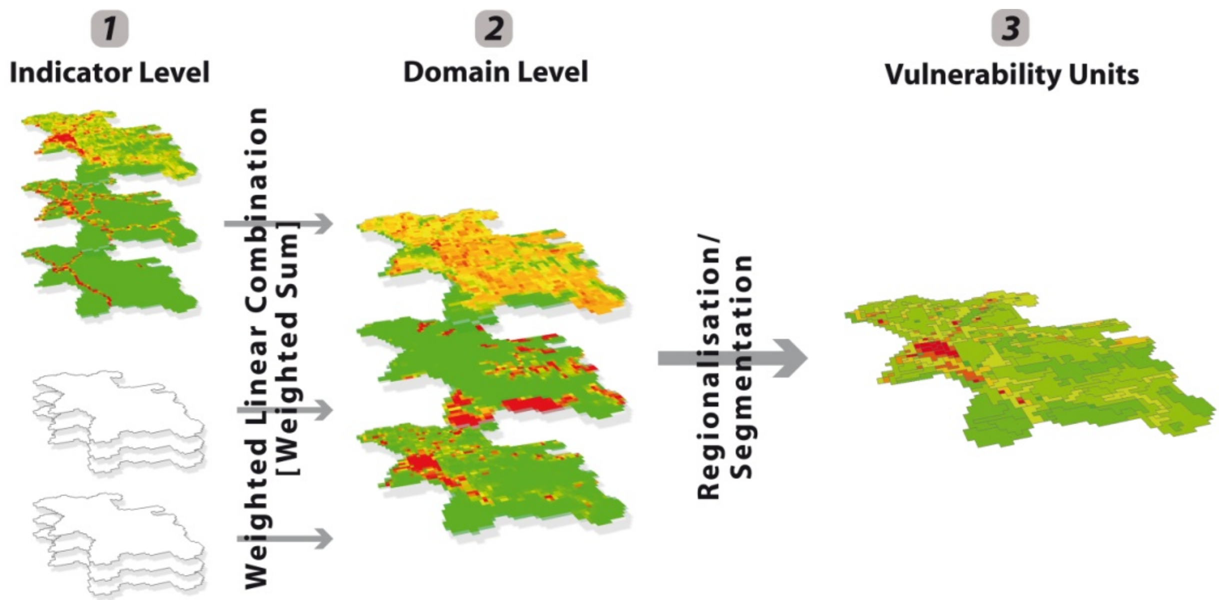

Figure 12. Flow chart visualising the composition of individual variables for the indicator SVU (flood) (Kienberger et al. 2009). The authors call 'indicator' what is called 'component and 'domain' what is called 'sub-indicator'or 'element' in this report.

For this test study the last aggregation step of regionalisation/segmentation was considered as not appropriate since the area of interest was not sufficient in extension and number of pixels. This working step was therefore replaced with a simple addition of values at sub-indicator level.

For the city Hamburg there was no information about early warning system available. Hence, the sub-indicator 'adaptive capacity' is calculated without this variable. The results of the application of the SVU for Hamburg and Salzburg are shown in Figure 13 and 14.

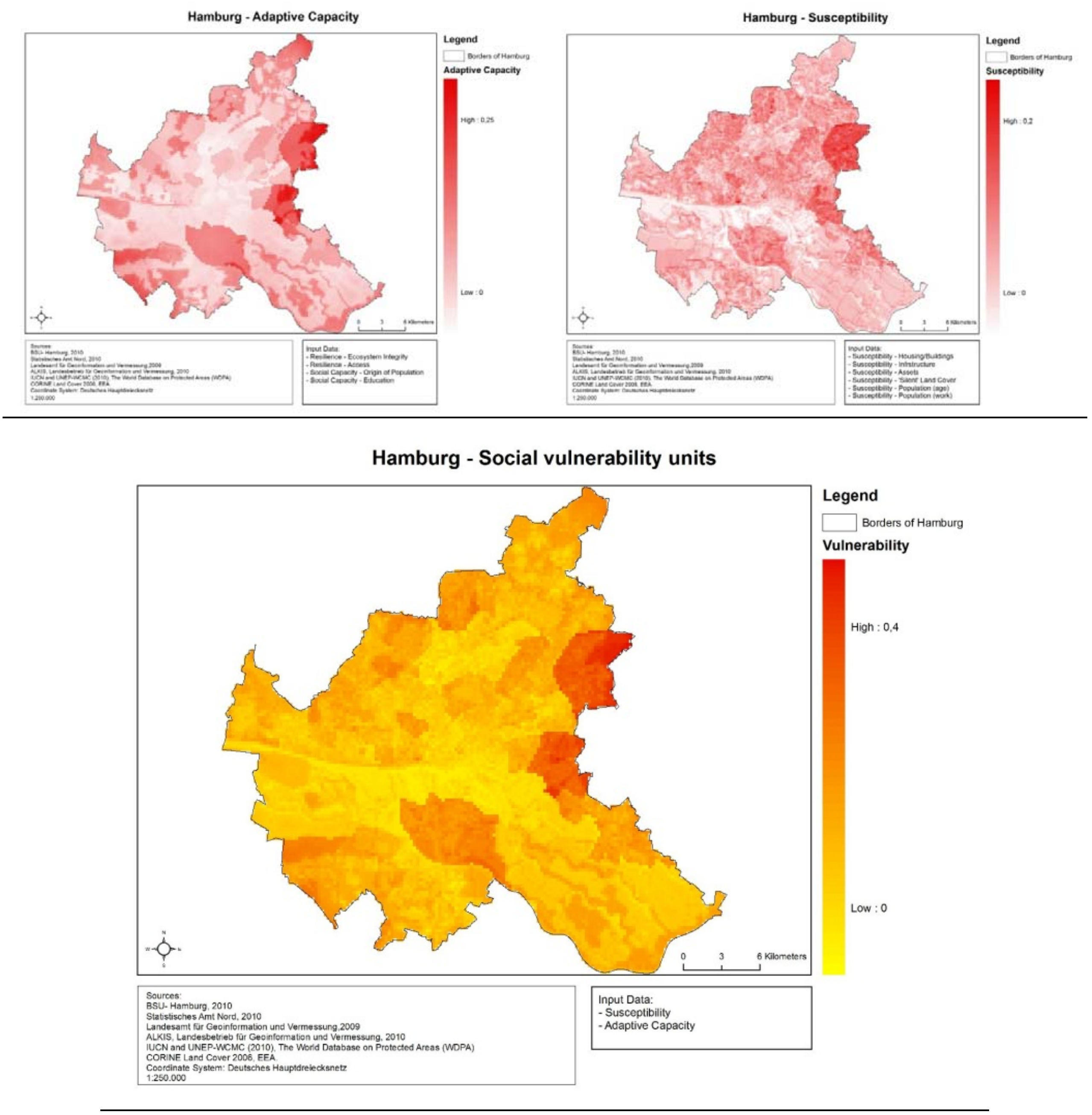

Figure 13. The results of the indicator SVU (flood) for the city of Hamburg.

(Data sources: Census data 2010- Statistik Nord (BSU), Digital Elevation Model - Landesbetrieb für Geoinformation und Vermessung (BSU), District Borders - Landesbetrieb für Geoinformation und Vermessung (BSU), Statistics of Graduates - Statistik Nord (BSU), ALKIS, Landesbetrieb für Geoinformation und Vermessung (BSU), CORINE Land Cover 2006 – EEA).

The map of the results of the calculation of the indicator Kienberger for Salzburg (
Figure 14) has directly been taken from the author. The spatial resolution of the results are lower than for the city of Hamburg (Figure 13) since the original area of interest for the development of this indicators was the whole Salzach catchment.

Figure 14. The results of the indicator SVU (flood) for the city of Salzburg.

5.5 Discussion

The results of the implementation of the RVI (heat) indicator (Kropp et al. 2009) in the cities Birmingham and Bolzano allow for a distinction of areas potentially exposed and sensititive to heat waves within the cities. It does not assess vulnerability in the sense as used by the IPCC since the component of adaptive capacity is missing. The capacity of the urban population to take measures against these impacts such as early warning, urban planning to avoid UHI effects, the installation of cooling rooms etc is not considered. The combination of the exposure component (the future heat wave days per year derived from climate scenarios) with aggregated values derived from physical (impervious area) as well as socio-economic data (population density, populations above 65 yrs) aggravate the interpretation of the final results.

Overall the variable 'Impervious area' influences the final results in a non-appropriate way. Reason for this is the development of the indicator for larger areas also comprising rural regions. The visualization of the results could be improved by applying filters that eliminate sharp borders between administrative units and linear features such as roads. Based on the climate scenario data the exposure of populations to heat waves is mapped for future years. However, the assessment of the populations' sensitivity remains static and is the same for all maps visualising future potential impacts since there are no socio-economic scenarios available.

The SSI (flood) indicator (Fekete 2009) focuses on social susceptibility to river floods. It has been developed for large areas and at county level in Germany. It does not assess vulnerability in the sense as used by the IPCC. Levels of potential flood events have therefore been added to the maps (as grey shaded areas) using existing hazard indication maps. The SSI maps exclusivly the current sitation and does not consider future vulnerabilities. The required data was not completely available for both case studies at sub-city level resulting in some white zones in the maps for Hamburg and Salzburg.

The SVU (flood) indicator (Kienberger et al. 2009) puts emphasis on populations' sensitivity and adaptive capacity to river floods. It does not assess vulnerability in the sense as used by the IPCC since the components of exposure is completely missing. In the same way as for the SSI (flood) the levels of potential flood events have been added to the maps (as grey shaded areas) using existing hazard indication maps. It is more complex than the indicator from Fekete (2009) with a much higher demand on available datasets.

Whilst the required data for the SSI in Hamburg could be derived from a large number of available datasets in a very tedious extraction work, the data for the individual variables for Salzburg was not available and the original results from Kienberger et al. (2009, which were kindly provided by Kienberger) have been mapped. Therefore the original spatial resolution of 1 km per pixel could not be improved. Also the comparability between the SSI and the SVU in Salzburg is hindered since the SVU results are of extreme high 'vulnerability' values due to the fact that they are generated as part of a larger context of the Salzach catchment area.

The comparison of the two flood indicators in Hamburg show in general a congruent picture, particularly those parts of the city with high susceptibility are identified in a very similar way. Differences are mainly due to the variation in spatial scale. The results of the case study Salzburg are hardly comparable due to the differences in spatial resolution and in the classes selected for visualisation, since for the SVU thresholds and colour schemes are chosen for representing the vulnerability in the whole catchment area. Nevertheless regarding to the SVU as well as the SSI, the inner city area is most sensitive. Data gaps at the periphery does not allow for comparison in the outskirts.

5.6 Conclusion

Chapter 5 identifies some of the challenges of developing vulnerability indicators for urban regions across Europe and also demonstrates the type of results that can be generated.

None of the selected indicators covers all three components of vulnerability as understood by the IPCC. The indicators SSI of Fekete (2009) and SVU Kienberger et al. (2009) focus on populations' characteristics that determine potential future harm and do not discount for the exposure component. The RVI developed by Kropp et al. (2009) is not considering social, cultural or institutional aspects of populations' sensitivity or their capacity to adapt to and cope with future changes. For a vulnerability assessment in the sense of the IPCC both approached need to be combined and the results of the individual vulnerability components should be spatially overlaid and only aggregated in a scientifically sound and transparent way.

The selected indicators – similar to the majority of other existing ones – attempt to assess potential future harm with variables and data describing almost exclusively the current situation except the RVI. The development of socio-ecological models for generating scenarios of future societal developments could support the assessment of potential future harm.

There are two main factors that limited the number of tested indicators and cities:

- Data availability
- Lack of details regarding the methodology

Data availability

All applied indicators are easy to compute once the required data is available and pre-processed. The data acquisition is tedious even if the amount of variables is very limited. Data acquisition for the various tested indicators reveals differences in data availability and access for the considered countries UK, Germany, Austria and Italy. Simplified it can be stated that the data for Birmingham was available online free of charge, data availability and access for Germany and Italy was limited and could only collected timely through personal network, data for Austria was available and accessible but rather expensive.

Although only rather simple indicators had been selected it was in appropriate laborious to acquire the necessary data. The amount of resources spent for data collection equalised that for indicator computation (given the time spent for identifying of and communicating with relevant administration officers, setting up data user right agreements assuring data flows etc). This is particularly true for the SVU and SSI, less for the RVI. In addition, the heterogeneity of datasets within the EU requires time consuming data pre-processing and hinders easy comparison (e.g. differences in the borders of age classes for demographic variables or the lack of basic socio-economic data in gridded format in most of the EU countries).

Methodological aspects

Although all indicators are described in publications certain details about the indicator aggregation/composition were not available. Authors were hesitant to reveal crucial details in order to not jeopardise future publication opportunities or for reasons of intellectual property rights.

There are two major aspects linked to **spatial scale** revealed by testing the indicators:

- The difficulty to combine gridded data such as climate scenario output with data linked to administrative units for which most of the relevant information about populations is available. The overlay of these two formats creates artefacts and forces to introduce working steps such as interpolation that increase uncertainty particularly when the spatial resolution of the gridded layer is relatively coarse and the dimension of the administrative units relatively large. Having access to gridded data even for socio-economic topics as it is the case in Austria helps to reduce effort and imprecision.
- The level of scale and the usefulness of respective data for vulnerability assessment need to be determined in advance. Even at the relatively sub-city level of this test studies it can be questioned in how far those data available at urban district level is able to detect most vulnerable population groups. Therefore the explanatory power of those data available for all European cities must be estimated realistically.

The tested indicators for sensitivity and adaptive capacity to the hazards heat waves and floods are predominantly useful for identifying hot spots of potentially susceptible regions or population groups. The differences in data availability (e.g. last update, size of administrative unit, way of data acquisition) case-specific characteristics (e.g. a rate of unemployment of 10% might be a high value in an Austrian city but not in an Italian one) introduce uncertainties that do not allow for direct comparison of 'vulnerability' values. They also do not reveal details about the underlying root causes but they might support decisions on where it is most urgent or promising to do future in-depth studies. Therefore it is necessary to remain realistic in expectations towards the results of composite indicator assessments.

There are also two major aspects regarding the **aggregation** level of the indicators:

- In order to receive values of vulnerability indicators the underlying variables must be aggregated. Usually this means combining values of various sources and units in a composed number or class of rather abstract character. For this working step no rules or agreed metrics exist. The aggregation steps carried out for this test studies were all simple as well as traceable and weighting factors were only given for the SVU based on stakeholder and expert opinion. Both, aggregation and weighting methods were evaluated as most appropriate.
- The results of the indicator assessments of this test study are values of one or several aggregation steps. They are valuable for highlighting certain aspects at abstract composition level. In order to be able to identify reasons for these final results and for any decision that might be made based on these results it is absolutely mandatory to also communicate the results of individual sub-indicator aggregation levels. Only with these additional information a comprehension of the aggregated indicator result is possible.

Aggregation is a necessary step when applying indicators but it should be implemented with care. Any aggregation method should be simple, easily reproducible and transparent for the user. Intermediate aggregation levels at for example factor or component level should always be visualised and communicated together with the final results. Particularly questionable is the composition (sum, multiplication or similar) of those variables describing external physical stresses such as future heat wave days per year with those datasets describing internal socio-economic, cultural or institutional aspects of sensitivity and adaptive capacity such as the access to information sources. Weighting of variables should only be done based on or at least verified by stakeholder and expert opinion.

There are two procedures proposed in order to implement a vulnerability assessment of urban areas at European scale:

1. Firstly, select most appropriate variables with the best coverage of European urban areas (if possible based on existing data bases such as EVDAB, see annex 7.2.1). Secondly, cluster these variables in order to cover the various components of the IPCC vulnerability term but do not specify any thresholds for classes, any aggregation method or any weighting factors. The generation of classes and the aggregation at various levels should finally been done in a case specific way with local/regional stakeholders and experts.
2. Firstly cluster cities in macro regions where urban areas possess similar characteristics considering for example exposure to potential external threats or sensitivity to external threats due to historical or geographical reasons. Secondly, select or develop indicators for these clusters separately (based on variables with the best coverage of urban areas relevant for the respective cluster). Finally carry out the indicator assessment and compare only within each city cluster.

6 Adaptation options of urban regions and cities

6.1 Introduction

Whereas the previous chapters have focused on vulnerabilities, this one looks into options to act.

The following sections analyse adaptation options for those climate change impacts expected to threaten cities and urban areas the most (IPCC 2007): droughts and heat waves (section 6.3), destruction by storms (section 6.4), and mainly water related threats such as heavy precipitation and flooding (section 6.2). Regional specifications such as fluvial flooding for coastal cities (section 6.5) or the impact of wild fires in the Mediterranean or Alps (section 6.6.) are getting increasingly in focus of city managers (OcCC 2003).

Consequently, cities and municipalities across Europe become increasingly aware of the particular impacts that climate change is expected to bear upon them. This is reflected by the rising evidence of meetings, workshops and projects, addressing the needs and essential activities of cities to be ready to adapt to climate change. The raise of awareness among cities now is essential, since many inevitable adaptation measures and options include the need of long-term planning to change the infrastructure, planning of built environment and multiple different logistics.

Most adaption actions and available options and their effects are not new: Building companies and spatial planners have always responded to external threats through improved building design and layout of cities. Green urban infrastructure was already in 1980 suggested to improve urban air quality and nature. Today, possible synergies between different sectors become increasingly known and can build foundations for cooperation. For example, green roofs and spaces provide multiple benefits for air quality, mitigation of excessive heat and enhancing biodiversity. Most of the proposed adaptation options are hard engineering solutions, which will continue to play a major role in adapting to climate change. But improved forecasting and preparedness, along with risk avoidance through planning controls and awareness raising become increasingly important. There is an additional over-arching need for improved high-resolution weather data for testing future performance of buildings, urban drainage and water supply systems at city scales (Wilby 2007).

The 2010 international conference “Deltas in Times of Climate Change”[10] concluded that an integrative adaptation approach is essential for cities to get ready for climate change. Climate adaptation offers a large quantity of economic opportunities and chances, such as mass retrofitting and innovative building approaches and the techniques and knowledge of experts are already available. However, the synthesis of knowledge and the applications, commitment and awareness for the need to adapt are still missing.

A lot of projects concerned with adaptation to climate change have started in the past few years and are still running. Some of these connect adaptation with climate protection research (e.g. ASSCUE, ERKLIM), others focus on the impacts of specific threats such as floods (e.g. RISK MAP, FloodResilienCity), water scarcity (e.g. AlpWaterScarce, DMCSEE), sea level rise (e.g. MARE, COASTANCE) or heat (e.g. KLIMES). Impacts in specific European Regions are addressed e.g. by CIRCE for the Mediterranean region, RESPONSES for coastal regions, or AdaptAlp for the Alpine region. Some projects investigate the adaption process as a

[10] 29 September - 1 October 2010, Rotterdam, the Netherlands

whole to support adaptation policy (e.g. ADAM) others are more concerned with the development or implementation of adaption options (e.g. BaltCICA, ESPACE). Only few projects are really focusing on adaptation options of cities and urban regions (e.g. CAT-MED, KLIMES, PLAN). Some of these projects are highlighted in the subchapters below.

Annex 7.2 and 7.3 of this study comprises a list of approx. 100 projects, dealing with vulnerability analyses, risk assessments and adaptation options – they are all launched in order to enable city planners and local decision makers to react on climate change.

The special situation of cities and reasons for their sensitivity

The sensitivity of European cities towards the impacts of climate change is significant. Functioning urban infrastructure and a healthy environment rely on complicated and extensive networks for transportation, water and energy, on communication, trade and sanitary provisional systems.

Economic characteristics are relevant in determining vulnerability: i.e. the value, density and quality of buildings and infrastructure, the quality of water supply, sewage systems and waste processing (Harvey et al. 2009, Corfee-Morlot et al. 2009) are highly endangered by extreme whether events. Other severe vulnerability factors in cities are related to the density and demographic and social characteristics of the population groups: Almost 15% of Europe's citizens are currently over 65 years old, showing an increase of 3% since 1980. Families with children, disabled and poor people, and the elderly tend to require especial attendance during or after extreme events (Mitchell 2003).

Different to rural areas, the dense concentration of buildings can lead to the 'urban heat island effect', which is already in the current climate problematic during summer times. This phenomenon is from increasing interest, as projected heat waves are anticipated to occur more often and more severe across Europe and will thus threaten large cities more often in the future (see section 6.3). Heavy precipitation events affect cities in particular, are as the high rate of sealed and impervious surfaces and buildings hinders surplus water from runoff, leading to severe flooding and destruction (Steinrücke et al. 2010, see section 6.2).

Cities are active: examples and options from early adapters

A survey among Danish municipalities indicates that climate change adaptation is high on the municipal agenda. Work is in progress to map and establish local climate change adaptation strategies[11] (Lund 2010, Hellesen et al. 2010). A survey of the German NGO 'NABU' revealed that at least 600 German Cities have green-management approaches already on their agenda.

Some early adapters have already finished or are working on their city adaptation strategy such as London (UK), Copenhagen (Denmark), Helsinki (Finland) or Tatabanya (Hungary). Other cities have started with an impact and vulnerability assessment such as Hamburg (Germany), Stockholm (Schweden), or Athens (Greece) to get an overview about the impacts of climate change and evaluate the most important threats for their cities. A lot of cities have already started adaptation activities by creating their own projects (e.g. Bonn (Germany), Bologna (Italy), Amsterdam (Netherlands)) or participating in national, interregional or European projects, e.g. the cities of Tiel, Nijmegen (both Netherlands) and Rouens (France) in the InterReg

[11] http://www.klimatilpasning.dk/en-US/Service/Newsletter/Sider/Climatechangeadaptationbylocalgovernment.aspx

IV B project *Future Cities*[12].

This study provides a list of "early adapters" and good practice examples of cities already implementing adaptation measures, provided in annex 7.5. At time of writing, the lists are comprehensive but certainly not complete, as new activities emerge on a constant rate and on small scale and as such information is not necessarily available.

Drivers and Barriers for adaptation in cities

Cities often take action in adapting to climate change in response to a extreme whether event or a series of more frequent or intense events that give evidence to a city's vulnerability to a particular phenomenon. This sense of need or urgency is a clear driver for cities to implement adaptation measures. The task of local governments (and particularly Mayors and Councillors) is to deliver municipal services to improve the quality of life of their citizens. However, the local government will be held accountable for negative impacts of climate change. Particularly economic interests, often linked to political success, carry driving potential.

Cities are in the privileged position to be able to implement measures and policies that aim to adapt to climate change directly at the local scale. This proximity to and knowledge of the urban systems allow local governments to understand the cross-departmental approach necessary to successfully introduce adaptation measures and to facilitate stakeholders' contributions.

> An example of easily feasible cooperation comprises solutions for water scarcity and droughts. A project to adapt to drought can involve the city urban planning department in designing new neighbourhoods in a less water-intensive fashion, the technical departments in re-evaluating the water treating facilities and detecting major leaks in the distribution system, the nature conservation department to find options and solutions for natural water storage and communications department in raising awareness to reduce the consumption of water among the population. This cooperation would be perfectly supplemented by other actors like e.g. water suppliers, home owners, building societies, and construction companies.

However, urban regions and cities face also complex obstacles when trying to implement measures to adapt to climate change: they can be categorized into physical, economical or technological issues. Existing city systems are per se a barrier to adaptation: Replacing or improving systems and the relocation of the vast amount of people is often extremely costly and difficult and can be accompanied by a lack of knowledge, warning systems and commitment.

A lack of political responsibility and commitment might be the most effective barrier on national- to communal levels. Although national governments often initialized national land-use planning frameworks and benchmarks, local governments can have different approaches, lack of consistent management and short-term orientation of political priorities. Further barriers towards adaptation can be the complexity of institutional and inter-juridical arrangements and the lack of personal, technical and financial capacity to assess and reduce climate risks. UKCIP samples a comprehensive list of other barriers and states: "To help

[12] http://www.future-cities.eu/de.html

overcome these barriers, it can be helpful to build adaptive capacity Improving the understanding of climate change, associated risks and vulnerabilities, along with actions related to understanding and updating the institutional and legal frameworks (i.e. those constraining or enhancing adaptive capacity)." [13]

6.2 Cities and urban regions facing heavy precipitation, urban drainage and fluvial floods

Particular threat

Heavy precipitation can lead to fluvial floods in cities, possibly resulting in urban drainage flooding. This forms a potential threat to European urban regions as the force and damage of water causes serious disruptions in socio-economic and environmental losses. Historical data learns that extreme whether events are nothing new across Europe. However, changes in precipitation patterns and magnitudes due to climate change can contribute to an increased occurrence of potentially damaging fluvial- and urban drainage flooding events by factor 30 (Jacobs et al. 2000; Arnbjerg-Nielsen 2008).

Urban drainage flooding

Heavy and/or prolonged rainfall produces very large volumes of surface water in any city, which can overwhelm drainage systems (IPCC 2007). Buildings, roads, infrastructure and substantial surface sealing prevent rainfall from infiltrating into the ground, producing a large amount of runoff. This surplus of water can cause traffic delays, destroy roads, flood houses and industries, it can cause electricity blackouts, and generally disturb public life. For the predicted future, traditional engineering measures alone are unlikely to maintain current service levels (Arnbjerg-Nielsen 2008; Ashley et al. 2005).

On the costs and occurrence of urban drainage floods in Europe, not much information is available. Local governments, however, increasingly initiate local research and action to prevent drainage floods on city- or neighbourhood scale. For example, Malmö, Rotterdam and London are involved in city designs promoting optimal water management and reducing the costs of urban drainage floods.

Fluvial floods

The dramatic impacts of urban flooding have proven to be large and to occur frequently, resulting from fluvial floods. Only recently, the rivers Var (France), Wisla (Poland), Neisse (Poland, Czech Republic and Germany) and Hornád (Slovakia) burst their banks in 2010. The impacts of destruction included significant damage of private and common property and infrastructure and caused several numbers of fatalities.

[13] http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=56&Itemid=9

Box I Major flood events

Between 2000 and 2005, Europe suffered more than 100 floods, including 9 major flood disasters. These major flood events caused 155 casualties and economic losses of more than € 35 billion. There is an increase in the frequency of years with very high damage produced by major flood disasters in Europe. Two years of the current decade, i.e. 2000 and 2002, are among the worst, concerning losses in the last 36-year period (Barredo 2007).

News BBC of August 8th 2010:

Flash floods brought on by rains in central Europe and the Baltic have killed at least 15 people.

Rivers overflowed their banks, sending torrents of water through Bogatynia in south-west Poland and Goerlitz in eastern Germany. Three Poles, three Germans and five Czechs were killed, while further north in Lithuania four people were killed. The same region was hit by heavy flooding in May and June this year, killing nearly 30 people.

Cases of fluvial flash floods occurred only recently in central Europe (see Box I) and are likely to increase throughout Europe (Adam project: Kundzewicz et al. 2009b). Projections show that several major European rivers, such as the Oder, Elbe, Po, Loire, and parts of the Danube, will be affected by so-called "100-year floods" more frequently by the end of the century (under the assumption of IPCC A2 scenario; Dankers and Feyen 2008, Arnbjerg-Nielsen 2008). However, in North-East Europe, the Iberian Peninsula and in several rivers in Central and Eastern Europe, the probability of a flood-event decreases (Kundzewicz et al. 2009a).

Analyses of EMDAT data (CRED 2003) for the decades 1973 - 2002 showed that the reported number of disasters caused by fluvial floods has dramatically increased in the UN European Macro-Region 2[14].

Figure 15 depicts an increase from 31 events between 1973 and 1982 to 179 events during the last decade. Fluvial floods caused 264 disasters during the whole period.

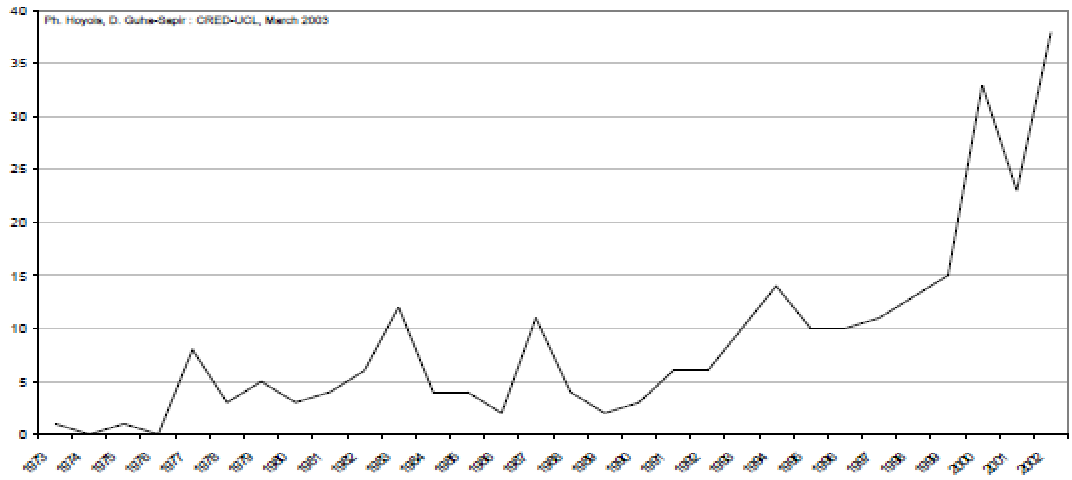

Figure 15. Total number of flood disasters reported: UN European Macro-Region 1973-2002.
Source: Hoyolx and Ouha-Sepir 2003**.**

[14] The United Nations Macro-Region for Europe is subdivided into Eastern Europe, Northern Europe, Southern Europe, and Western Europe.

In 1997 Poland and Czech Republic lost approximately EUR 5.2 billion due to flooding events. Italy, France and Switzerland experienced losses of EUR 9.2 billion in the year 2000. In 2002 the flood damage recorded in Germany, Czech Republic and Austria reached EUR 17.4 billion and was higher than in any single year before. And the cost of floods in the UK in summer 2007 has been estimated at around EUR 4.3 billion. The annual average flood damage in Europe in the last few decades is about EUR 4 billion per year (Barredo 2007).

In 2010, early cost estimates from the governors of the hardest hit Austrian provinces are €3 billion. In the Czech Republic the damage is expected to be €2 billion. The German Farmer's Association estimates nationwide grain losses up to €1.5 billion, which is likely to cause higher prices for fresh food (BBC-News 2010).

The increase in reported damage seems to be caused by a combination of factors of which urbanization and climate change are most relevant (project 'The Flood Resilient City', 2010). Although economical losses related to fluvial floods have increased around the globe, they are often due to changes (increases) of population and economic goods at risk in floodplains (Bouwer 2010).

To give an example, the costs of the summer 2007 floods in the United Kingdom reveals summed up to £3.2bn, including more than £2bn to homeowners and businesses. The average cost for homeowners was between £23,000 and £30,000, 30% of households were forced to relocate to temporary accommodation. The average cost incurred per flooded business was between £75,000 and £112,000. Other large costs were for infrastructure and utility companies (DEFRA 2010).

Particular sensitivity and vulnerabilities of Cities towards flooding

Urban drainage flooding

Urban drainage flooding occurs primarily because of inadequate sewer systems and/or city planning (Schmitta et al. 2004). Due to the increasing value of property, buildings and infrastructure prolonged flooding can cause a lot of socio-economic damage.

A pilot project by DEFRA, UK called 'Making Space for Water: Urban flood risk & integrated drainage' (Gill 2008) acknowledged the complex physical and institutional factors that result in flood risk due to pressures from climate change and increasing urbanisation. Other publications on sensitivity and vulnerability that address urban drainage floods are rare.

Fluvial Floods

Fluvial floods are natural phenomena which cannot be prevented. However, human activity such as clearing forests in the upper catchment areas, straightening of rivers and suppression of natural flood plains and inadequate drainage practices are contributing to an increase in the likelihood of extreme flood events.

Cities are often initially built along the shores of a river for the purpose of transport and water supply. Over time they have been merging culturally and physically with the water that contributes to their wealth. In order to tame the natural dynamics of the river, dams, dikes and concrete shores have been constructed to limit damage and discomfort during high water events. This however created hydrological 'bottlenecks' that influence the rivers character upstream and downstream from a city, leading to increased risk of flooding. Additional, for flash floods, warning time is often short and evacuation is not always possible. The water flow and the large debris that floods may contain can destroy buildings, and infrastructures such as roads and railways, leading to perturbation in transportation (OECD 2006).

The urbanisation of downstream floodplains by export-orientated businesses and industries along navigable waterways that connect with deep water ports is an example of increasing exposure to flood risk. This process takes currently place, for example, in the Thames Valley (UK), Rhine valley (Germany) and to a lesser extent along the Elbe (Germany) and the lower Seine (France) (Mitchell 2003).

Recently, the "old river cities" of northern Europe, such as Hamburg, Manchester, Paris, Rotterdam or London engage urban clearance and redevelopment projects to improve their own capacities in flood hazard potential. Low-value investments at risk to flooding are replaced by high value real estate with safeguard measures applied. All across Europe, growing European affluence is multiplying the value of buildings, infrastructures, services, and amenities (Mitchell 2003).

Geographic distribution

Urban drainage flooding

Quantitative projections on changes in precipitation in Europe because of climate change are highly uncertain. However, flash floods and urban floods, triggered by intense local precipitation events, are most likely to be more frequent throughout Europe (EEA 2008) in the future.

Fluvial floods

The geographical distribution of fluvial floods is highly dependent on the hydrological system and the adjacent human activities. However, the increased occurrence of extreme flood events cannot exclusively be ascribed to climate change.

Flood events are likely to increase in coming winters, were more frequent rain and less snow are projected. Even in regions which decreasing mean river discharge, a projected increase in precipitation can cause an increase in flood events. In snow dominated regions like the Alps, the Carpathian Mountains and Northern Europe, floods are projected to decrease due to a shorter snow season and decreasing snow accumulation during the winter (EEA 2008).

Adaptation options

Urban drainage floods are studied in cities like Malmö, Rotterdam and London. The adaptation options are very similar to those for fluvial floods with the exception that the scale is different. The main driver for action is the need to drain the cities as fast as possible after flooding events.

On the smaller city scale some extra adaptation options are being implemented. By incorporating natural principles, e.g. the city of Malmö (Sweden) manages rainwater flows with a new open 'storm-water-system'. Here, green roofs and open water channels lead rainwater into collection points that form a temporary reservoir for the surplus of water.

Also in Rotterdam, open water channels used in newly built neighborhoods channel the water flow and increase the drainage capacity. Adaptation options in cities are based upon a retention system or a fast draining principle, requiring much space.

A number of European cities, areas or regions at risk to fluvial floods have successfully implemented adaptation measures or are in the process of doing so. The adaptation options presented here are representative for the majority of adaptation options analyzed in this study. The following examples offer an overview of local adaptation options where most adaptation projects are involved in analyses on higher scale.

Examples of already finished and ongoing projects involve:

Integrated transregional water management

The province of Limburg and the Flemish Land Agency, Belgium, cooperate within the InterReg project "F:ACTS!" (2010-2012) to develop a territorial strategy for climate change adaption in DeWijers. Here, flooding occurs occasionally and leads to a surplus of waste water flowing into surface water and polluting the vulnerable Natura 2000 pond systems of DeWijers. An increase in both extreme flood risks and serious water shortage during hot and dry summers is expected. To cope with extreme water fluctuations, the project aims for a flexible water management in the DeWijers catchment. Main adaptation measures consist of maximizing synergies of different land-use forms by cooperating on an transregional scale.

Risk based management

The City of Orléans, the Val de Loire Conurbation, and the Loiret Departmental Council, France, are working together in the project "FloodResilienCity". The aim of the project is to raise awareness of the potential impact of flooding by the River Loire within the public, among stakeholders and with government and decision makers. The goal is to reduce the risk of wealth destruction and human health impact by increasing the resilience of buildings and infrastructures and by preparing evacuation and recovery plans preventively.

Increasing space for water

The Dutch government has initiated the program 'Room for the river' in 2006. By providing more space for water around Dutch rivers, flood risks will be reduced. One of the projects involved is 'Room for the Waal' in Nijmegen. The Dutch government has decided to build an inland dike replacement alongside the river Waal in Nijmegen as best solution to reduce the flood risk (The FloodResilienCity, 2010).

Optimise flooding pathways

The basin of the Dijle River source is situated half-and-half in the Walloon and the Flemish region in Belgium. Because of a high risk of flooding it was decided to combine the natural flooding area in Neerijse (downstream) with an artificial flooding area in Egenhoven (upstream). This water management system is designed to protect the city of Leuven against a "100-year" rainfall event (The FloodResilienCity Project, 2010[15]).

Barriers and drivers

The process of adaptation to flood risk is prone to various barriers.

An approach to limit the risk of urban drainage flooding in most cities is an assessment of current problems and the identification of vulnerable hot-spots. A pilot project by DEFRA, UK called 'Making Space for Water:

[15] Project FloodResilienCities, 2010; http://www.floodresiliencity.eu

Urban flood risk & integrated drainage' (Gill 2008), data availability was poor and formed a significant barrier for successful adaptation. Institutional arrangement and responsibilities, although very different throughout Europe, make it very difficult to fund and coordinate necessary adaptation options. Although the risk of flooding is understood and tangible, some stakeholders lack the financial capacity or power to take appropriate action. The widespread adaptation process is further delayed by the need of locally tailored solutions of e.g. urban drainage systems. The spatial planning for such needs can take a very long time.

The process that aims to protect society from the impacts of heavy precipitation and fluvial floods can be categorized into physical, economical or technological issues.

The physical hydrological characteristics created by static urban structures can be regarded as one barrier to adaptation, the allocation of property and people as an other. To accord a river the natural space it needs would limit flood damage, but relocation of people, property and business is in many cases the only option. This option, however, is often economically unfavorable in urban areas.

Cities development and spatial planning have a tendency to utilize the floodplains adjacent to rivers. The project ALFA (Adaptive Land use for Flood Alleviation, 2007-2013) recognizes that spatial planning competes with flood protection. It identifies the problem and raises awareness, and provides technical solutions and measures. As pilot regions the floodplains of the rivers Seine (France), Rhine and Emscher (Germany) will try solve the conflicts between urbanization and flood risk.

In summary, main barriers for suitable adaptation measures are limited available space, existing building structures along the rivers and in the flood plains and expensive long-term perspectives in spatial planning.

6.3 Cities and urban regions facing temperature increase, water scarcity, droughts and heat waves

Particular threats

Droughts and heat waves are among the most destructive and devastating meteorological phenomena worldwide, causing major fatalities throughout history (Goklany 2006). In Europe, heat waves and droughts have claimed 76,646 human lives in the first decade of the 21st century, whereas floods and storms killed 1,500 people during the same period[16].

Although droughts and heat waves have similar characteristics and are often associated with one another, they are two different climate threats and distinct in both their causes and formation. They may occur simultaneously, one triggered or sustained by the other, but it is not uncommon for one to be present independently of the other due to separate meteorological triggers.

In cities, heat waves with high temperature extremes and urban draughts with associated water scarcity negatively affect economic activities such as energy supply, buildings and built-in areas, transport systems,

[16] EM-DAT, International Disaster Database, Center of Research for the Epidemiology of Disasters (CRED), http://www.emdat.be

water supply, and food supply. Urban green areas, ecosystems and biodiversity are also affected severely (Parry et al. 2007). Additionally, droughts concern the systems of sewage and drainage (Martin-Ortega and Markandya 2010, REC 2007), whereas heat waves distress communication systems and solid waste treatment (World Bank 2008b; see also section 3.3 and annex 7.1.2). Within the urban environment the impacts on human health and life is particularly severe (Wilhelmi et al. 2004; Matthies et al. 2008, see Box II).

Box II Sufficient water for Ankara, Turkey?

In Ankara, intensive drought conditions occur at least once in each eight-year period, the last being in 2007. Although such events are natural, the situation of Ankara has changed dramatically: from a small town with some 74 000 inhabitants in 1927 it became a metropolis with more than 3 million inhabitants by 2000, expanding its area more than 650-fold. This growth is expected to continue, and water consumption per person is expected to increase dramatically as a result of changing lifestyles and economic activities. However, the water resources are limited and insufficient to meet already current demand. Climate change, with an expected decrease of annual precipitation and river discharge in the region, is projected to further aggravate the situation and make a drought management plan a priority (Ceylan 2009).

Worldwide the number of heat waves has increased and became widespread since 1950 (IPCC 2007). The European climate assessment (Klein-Tank et al. 2002) confirms that Europe has experienced an unprecedented rate of warming in recent decades. From 1976 to 1999, the annual number of warm extremes increased twice as fast as expected based on the corresponding decrease in the number of cold extremes. The frequency of very hot days for instance in central England has increased since the 1960s, with extreme summers in 1976, 1983, 1990 and 1995 (Hulme et al. 2002). Sustained hot days (taken as heat-waves) have become more frequent, especially in May and July.

In the last thirty years, EU has been affected by major droughts, in particular in 1989, 1990, 1991 and 2003. Italy, Portugal, Cyprus, Spain and France have registered the highest frequency of droughts from 1976 to nowadays, with a range of 8 to 21 events by country). Since the year 2000, Europe has observed four major heat waves, namely in 2003, 2006, 2007 and 2010. Between 2000 and 2006, 15% of the EU territory and 17% of the EU population have been concerned on an annual basis (EC DGEnv 2007). A severe 4 year long drought (2004-2008) has affected the South of Europe and Turkey, severely affecting cities such as Ankara and Istanbul (Turkey), Barcelona and Saragossa (Spain), Belle-Ille (France), and others.

The Forth IPCC Assessment Report states that heat waves will became lengthier, more severe and more frequent in Europe until 2100 (Parry et al. 2007, Meehl and Tebodi 2004, Huth et al. 2000). These conclusions are drawn from global models and the downscaling to regional high resolution climate scenarios for European macro-regions. The regional scenarios are developed under a number of big interdisciplinary projects[17] . They provide the regional projections, modeling inter alia temperature

[17] PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects), MICE (Modeling Impacts of Climate Extremes), CLAVIER (Climate Change and Variability: Impact on Central and Eastern Europe), ENSEMBLES (reliable quantitative risk assessment of long term climate change and its impacts), STARDEX (Statistical and Regional dynamical Downscaling of Extremes for European regions), CECILIA (Central and Eastern Europe Climate Change Impact and Vulnerability Assessment).

extremes and precipitation extremes (Christensen et al. 2007).

Particular sensitivity and vulnerability

The sensitivity and vulnerability of the urban population and urban systems to the impacts of heat and droughts can be described by the following main issues of sensitivity:

Geographic location of a city plays an important role in the sensitivity of its population for heat waves and the long term temperature trends. There is no single universal threshold temperature above which the rate of heat related morbidity and mortality increases sharply. Instead, tolerance of excess heat varies regionally according to the population and its preparedness for hot weather and according to the local average temperatures and frequencies of extremes (McMichael et al. 1996). For instance, the population of cities accustomed to high temperatures as e.g. in Southern Europe shows bigger resilience to heat than people e.g. in London (Pattenden et al. 2003).

The individual place of residence within a city can trigger thermal stress. Urban heat islands (see Box III) leave population inhabiting affected areas in dense city centers more vulnerable to heat stress than the residents of suburbia and rural areas. The main threat of urban heat islands is the lack of cooling temperatures during the night time (Wilhelmi et al. 2004). This threat is further exacerbated by the fact that weather forecasts cannot model the extra heating of urban heat islands (Betts and Best 2004).

Particularly vulnerable social groups in cities comprise the elderly, especially women above 65 years old, infants, women in the last trimester of pregnancy, and people with low income as the latter is generally associated with poor quality accommodation and restricted access to information and air-conditioning facilities. Other vulnerable groups are people with professions related to outdoor activities, people living on top floors and south-exposed apartments, ethnic minorities, disabled people and people with chronic health conditions (D'Ippoliti et al. 2010).

An increase in awareness of the local population on the impact of excessive heat on the human health and simple affordable measures to prevent excessive heat stress can make local population less sensitive to the heat waves (Ebi et al. 2004, Matthies et al. 2008).

Meteorological local conditions within cities can exacerbate the impact of heat waves. Among them are humidity, wind speed and direction, and fluxes in both short- and long-wave radiation. The higher the moisture, the higher are the rates of morbidity and mortality. Lack of wind and, hence, ventilation as well as higher radiation are factors of urban heat islands enhancement (Wilhelmi et al. 2004).

Timing and intensity of the heat waves can render population more vulnerable. Heat waves that occur earlier in the summer usually exhibit higher mortality rates, primarily because the human body has not had time to acclimate to the inclement climate (D'Ippoliti et al. 2010).

Box III Urban Heat Islands

The term ‘‘urban heat island’’ has been used in climate research primarily to describe differences in background surface temperature between urban areas and rural surroundings. A temperature gradient between an urban area and nearby rural land can often reach up to 10°C. The development of built infrastructure could significantly alter temperatures, humidity, winds, visibility, radiation, and other meteorological parameters in urban areas. The causes of the urban heat island can be related directly to the integrated effects of the net albedo (reflectivity) of the urban surface, the thermal storage capacity of the urban physical infrastructure and remaining natural ecosystems, gaseous and particulate air pollutants, and the interaction of boundary layer winds with topography and infrastructure (Wilhelmi et al. 2004).

Geographic distribution

In Europe, the most vulnerable regions towards heat and water stress are the Mediterranean, Southern Europe, the Balkan area, and Central Europe (Parry et al. 2007). However, current heat waves also affected the Northern Hemisphere, indicating a starting change in the known patterns.

The effect of heat waves shows great geographical heterogeneity among cities. The increase in mortality during heat wave days in 2003 ranged from an increase of +7.6% in Munich to +33.6% in Milan (Michelozzi et al. 2007). The increase of mortality was up to 3-times greater during episodes of long duration and high intensity. Pooled results showed a greater impact in the Mediterranean area (+21.8% for total mortality) than in North Continental cities (+12.4%) (Michelozzi et al. 2007).

As mentioned above, tolerance of excess heat varies regionally (McMichael et al. 1996). Even within the same regions the city specific temperature change thresholds beyond which the increasing temperature yields increasing mortality rates (Temperature Changing Points, TCP) also demonstrate heterogeneity especially in the Mediterranean region. A main North-South tendency though remains: the average TCP of Northern cities are 6.1°C lower than in Southern cities (Table 12).

Table 12. City Specific Temperature Changing Points. Source: Baccini et al. 2008.

Athens	Barcelona	Budapest	Dublin	Helsinki	Ljubljana	London	Milan	Paris	Prague
32.7°	22.4°	22.8°	23.9°	23.6°	21.5°	23.9°	31.8°	24.1°	22.0°

Rome	Stockholm	Turin	Valencia	Zurich	North Continental	Mediterranean
30.3°	21.7°	27.0°	28.2°	21.8°	23.3°	29.4°

Adaptation options

The development of a Heat Health Watch Warning System (HHWWS) can be considered as a long term adaptation option to address heat waves and hot temperature events. Successful systems comprise (Matthies et al. 2008):

- An agreement of a leading body to coordinate a multipurpose collaborative mechanism between bodies and institutions and to direct the information if an emergency occurs;
- Accurate and timely alert systems (heat-health warning systems trigger warnings, determine the threshold for action and communicate the risks);
- Heat-related health information plan (about what is communicated, to whom and when);
- Reduction of indoor heat exposure (medium- and short-term strategies; advice to public on how to keep indoor temperatures low during heat episodes);
- Particular care for vulnerable population groups;
- Preparedness of the health and social care system (staff training and planning, appropriate health care and the physical environment);
- Real-time surveillance and evaluation of measures.

After the heat wave of 2003 several countries such as France, Hungary, Portugal, and UK established national HHWWS. In Spain a HHWWS was established at the regional level, in the province of Catalonia, and several German federal states also reported the existence of such systems. A number of municipalities across Europe have established similar systems adopting the national elements feasible for them (e.g. Madrid, Barcelona, Paris, Lyon, Marseille, Rome, Milan, Verona, London, Philadelphia, New York). For instance, in Budapest and Tatabanya, Hungary, such systems were already proved to be successful. Coupled with a Smog Alert System and an UV Alert System, the "Heat Alert" in Budapest showed success in 2007, when excess mortality due to the extreme event has been lowered in comparison to 2003 (Paldy and Bobvos 2010). In Tatabanya the HHWWS is a part of the city's "Climate Change Action Plan".

Under HHWWS all relevant municipal stakeholders (e.g. municipal departments, meteorological services, hospitals and other medical institutions, schools, kinder-gardens, transport companies, mass media, local environmental protection organizations, companies) have their own "protocol of activities" and the mandate to carry out these actions in case of a heat wave.

It proofed to be from great importance to inform the population via mass media in case of heat events. TV and radio stations can broadcast medical advises on how to minimize the risk of hyperthermia by simple means, such as to dress up in light clothes, cover the head, drink enough water, or search for the nearest air-conditioned public building. Hospitals action plans hold to get prepared to an expected increased inflow of patients with cardio- and respiratory diseases.

Further activities involve spraying of roads and pavements with water for cooling purposes, distribution of free drinking water at the main transportation hubs and enforcement of additional breaks for workers performing tasks in open air every hour. In Budapest, the municipality coordinates all such activities.

In Paris the City Council's Plan Climate encourages elderly and disabled citizens to be listed on a extreme heat special register CHALEX. Through an emergency call number these vulnerable groups can acquire information on heat stress prevention measures and seek a home visit when necessary.

Due to the expected increase in the number of hot days and incidents of heat waves, it is anticipated that the demand for air conditioning is going to increase. Through the implementation of the Eco Labeling Directive and awareness raising campaigns general public could be motivated to purchase the most energy efficient air conditioning systems. Adaptation options for district cooling address the increased demand for air-conditioning in an energy-efficient way on the district or city scale by (i) prioritizing absorption cooling (which allows the use of excess heat from other processes) over compression cooling (which mainly uses electric energy); (ii) using district cooling instead of local cooling. In Vienna, as well as in Dresden, both options are also combined with each other.

A number of municipalities across Europe have decided to combine adaptation and mitigation activities. They include regulations and building codes for insulation, efficient energy and water supply systems, and concepts of “green roofs” in urban development. For example in Bologna, the new building regulations introduce a requirement to include many plants outside of new buildings and to use pale coloured roofs to increase the albedo effect.

Manchester City and London, UK implement "green roof programs" in partnership with private building contractors. ’Green roofs' are meanwhile considered across European cities, e.g. in Nijmegen, Rotterdam, Vienna or Warsaw. They can be a part of the solution to the contradiction between the need for 'green zones’ and recreation areas and lack of space in the city centers. Conservation of the existing “green” and “blue” spots (water) in the cities and creation of the new ones is a no-regret adaptation option, to prevent urban heat island effect and protect biodiversity in the urban areas. Moreover, good insulation for top floor flats is combined with the retention of rain water, which, in turn, can be used for technical purposes or by the inhabitants of the buildings.

New constructions should also be required to have energy-efficient HVAC (Heating, Ventilation, Air-Conditioning) systems and appliances as well as high quality windows and grey water recycling. New building codes have been approved in Bologna and Saragossa in order to promote the usage of water-efficient technologies and devices in new houses and the installment of rainwater collection systems. Choice of appropriate construction materials, thermal storage of heat in building materials is an important consideration in the urban energy balance and in mitigation of hot season human health impacts. Energy stored in built infrastructure is released only slowly during night times, such accentuating the nighttime urban heat island. Also the traffic is affected by severe heat events, e.g. rail transport was reported to be regulated by speed limits to address rail deformation.

Insurance companies can provide a contribution to minimize at least economic losses of the heat waves (Dousset et al. 2009). They can do it more efficiently with support of geospatial technologies.

The problem of water supply, urban waste water treatment and water efficiency during droughts was addressed in a study carried out for the European Commission (EC 2010). It assesses the risks and impacts of alternative water supply options i.e., desalination, wastewater re-use, ground-water recharge, and rainwater harvesting. The study revealed that it is not possible to provide an EU-wide set of best available mitigation options, further more the first three options are costly and need to be addressed to the national scale rather than on municipality scale. The same is true for the re-allocation of water resources from water-rich regions to water-stressed regions. Projects for permanent infrastructure for this purpose are planned in Spain and in Turkey. However, neither Barcelona not Ankara or Istanbul can afford such investment on their own. Whether these projects represent mal-adaptation or not is still under discussion.

What municipalities can afford is the emergency water supply by means of water tanks or bottled water. This was applied in Barcelona (Spain) in summer 2007, in Belle-Ille (France) in 2005, and in Istanbul and Ankara (Turkey) in 2007 and 2008.

The problem of water scarcity in urban areas needs to be eased on supply side and on end-users’ side. Awareness raising for responsible consumer behavior together with measures to foster better water management must include the improvement of existing supply systems, leakage reduction, installation of metering equipment, proper water pricing and taxation systems, and reuse of waste-water and soil protection.

Barriers and drivers

There are two major drivers for the enhancement of adaptive capacities in the urban areas.

The first one is the increased frequency of the heat waves in Europe in the first years of the century. General public as well as local authorities might currently not consider the increased frequency of heat waves and droughts as a consequence of climate change per se but they cannot deny any more that this is an environmental challenge needed to be dealt with. Therefore, the establishment of Heat Health Watch Warning Systems and accompanied action plans is a logical step.

The second major driver is the involvement of international organizations and the institutes of the European Union into environment-related activities. For instance, a project titled EUROHEAT (2006-2007) has been co-financed by the WHO and DG Public Health. The project assisted to create detailed guidelines for the establishment of "Heat Health Watch Warning Systems" (Matthies et al. 2008) as well as a website where an eight-day probabilistic forecast of temperature is available for entire Europe (http://www.euroheatproject.org/dwd).

The EU also facilitates the adaptation process through its environmental though non-climate regulations such as Water Framework Directive (2000/60/EC), Flood Directive (2007/60/EC), Energy Performance of Buildings (2002/01/EC), Ecodesign Directive (2009/125/EC), Spatial Planning requirements, Common Agricultural Policies and others. Numerous research projects financed through the institutions of EU assist to prepare the ground for practical actions bringing together scientists and practitioners.

Among the barriers on the way for implementation of adaptation options, is the lack of awareness among authorities and general public. This is accompanied by the uncertainty on future frequency and effects of heat waves on the quality of life in urban areas, a lack of information on available adaptation options, a lack of political will and appropriate institutional capacities to coordinate possible stakeholders. This all is severely negatively influenced by a lack of sufficient financing. Some research mentions the absence of an integrated approach to reduce social vulnerability as a barrier. They advice to excess heat as a function of both natural and social systems via both physical and infrastructure based and social measures (Wilhelmi and Hayden 2010).

6.4 Cities and urban regions facing storms

Particular threats

Severe weather is defined as weather conditions with waterspouts, damaging wind gusts, large hail or tornados, which minimum intensity of 26 m/s or hail diameter of at least 1.9 cm (Johns and Doswell, 1992; specific quantitative criteria vary by country in Europe). Lightning and thunder are not generally included in the definition of severe weather, although they commonly occur in association with severe weather storms (Rauhala and Schultz 2009).

Broad consensus exists amongst scientists that climate change will lead to an increase in the frequency and intensity of extreme weather events such as storms (IPCC 2007). A survey conducted by one of the world's largest reinsurance agencies, the Munich Re, shows that almost three times as many weather-related natural catastrophes worldwide happened in the last decade compared to the 1960s. Economic losses increased over five-fold in the same period (Munich RE 2010)(see Box IV).

Multiple projections from Global Climate Models (GCM) and Regional Climate Models (RCM) have been produced in the ENSEMBLES project with respect to future changes in wind storm risk (Leckebusch et al. 2008; Donat et al. 2009a); and related loss potentials (Donat et al. 2009b). The research indicates that increased extreme wind speeds over northern parts of Central and Western Europe are expected under increased greenhouse gas forcing. On the other hand, decreased values of extreme wind speeds are projected for Southern Europe. Consistent with projected changes in extreme wind speeds, higher storm losses are estimated for Western and particularly for Central Europe, assuming that no adaptation to the changed wind climate takes place (Figure 16).

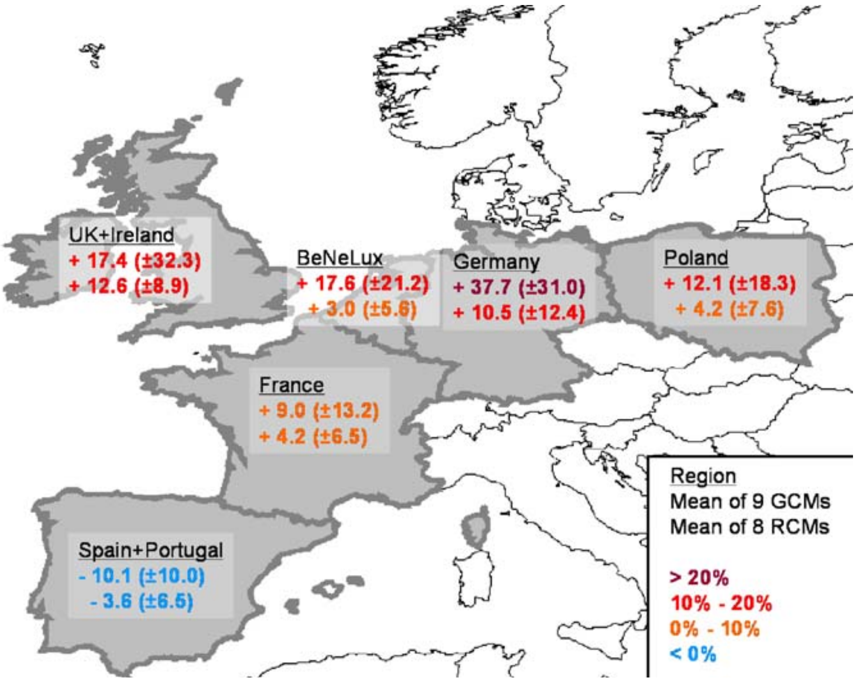

Figure 16. Relative changes (%) of mean annual storm loss potential based on nine GCM (upper row) and eight RCM (bottom row) simulations for 2071-2100, compared to 1961-2000 (assuming the SRES A1B scenario).
Source: Donat et al. 2009b

Particular sensitivity and vulnerabilities

Weather-related natural disasters have major consequences for society and economy. Cities and urban regions are vulnerable to damages caused by storms in several ways. Strong winds can destroy the transportation, communication, water and sewage infrastructures. Stormy wind can be strong enough to uproot trees, roofs and utility poles, causing them to fall on people, buildings and vehicles. Such incidents have already caused deaths, and have left houses uninhabitable, during several incidents in Europe. The major winter storms in Europe since 1980 are summarized in Table 13 indicating caused damage and fatalities. Due to strong wind gusts, the energy sector suffers impact, as power generation (fossil, nuclear and renewables) infrastructure and energy distribution systems can be flooded, damaged, or lose efficiency (Michaelowa et al. 2010). Extreme precipitation during storms can cause river floods, causing property and agricultural losses. Several studies have proved that urban storm water is heavily polluted and that storm water pollution is comparable to wastewater pollution (Saget et al. 1995; UNESCO 2001). Water running off these impervious surfaces tends to pick up petroleum products, heavy metals, pollutants, fertilizers, pesticides, polycyclic aromatic hydrocarbons (PAHs), and synthetic organic compounds (Burton and Pitt 2001; Alexandria and Weston 1998). Storm surges can also have disastrous effects in susceptible coastal cities, causing major flooding and widespread damage. The details of the vulnerabilities of coastal cities and urban floods are presented in Chapters 6.2 and 6.5. Other vulnerabilities include fires due to lightening events and damage or destruction of roads due to landslides after heavy rain and floods (ECMWF).

Box IV Winter Storm Kyrill caused the largest insured loss from a winter storm event to date in Germany

In January 2007, the severe winter storm *Kyrill* affected many areas of northern Europe, crossing from the UK into northern Germany and continuing eastwards to affect Poland, the Czech Republic, and Austria (Source: ECMWF).

Extreme winds caused extensive damage over large areas. Thousands of homes and public buildings were damaged, basements flooded and trees and power lines broken. The electricity broke down in millions of households, roads and bridges were blocked. The traffic on all infrastructures (rail, road, air, river and sea traffic) was severely interrupted for hours, schools had to be closed, and industry was largely affected. For example the Druzhba Oil Pipeline broke down, causing 1,600 m^3 of oil to escape. With total losses of approximately $10 billion, *Kyrill* is ranked as the second most expensive natural catastrophe worldwide in 2007 (ECMWF), although range forecasts gave early warning of an approaching storm event.

Based on the ECMWF forecasts, the German Weather Service, DWD, issued advance warnings five days ahead. This provided the disaster management agencies with key planning information, enabling the Federal Office for Civil Protection and Disaster Assistance to set up an emergency task force, and giving time for staffing levels to be increased in crisis management centers.

In 1999, total losses due to windstorms in Europe exceeded €23 billion, from which the storms *Lothar* and *Martin* constituted €12 billion, causing catastrophic damage to property, forests and electricity distribution networks. *Lothar* alone killed 110 people (Munich RE 2010).

In winter, thunderstorms are dangerous particularly for air traffic, as storms cause the cloud base to rapidly fall and reduce visibility due to heavy snowfall. Combined with hail, such storms pose danger also for the urban areas around the airports, especially when the planes are landing (EMCWF).

Table 13. Significant winter storms in Europe, 1980 until June 2010

(Source: Munich RE, Geo Risks Research, NatCatSERVICE).

Period	Event	Affected Area	Overall losses	Insured losses	Fatalities
			US $ Million, original values		
26.12.1999	Lothar	France, Germany, Switzerland, Belgium, Austria	11,500	5,900	110
18-20.01.2007	Kyrill	UK, Germany, France, Netherlands, Belgium, Denmark, Austria	10,000	5,800	50
25-26.01.1990	Daria	Belgium, Denmark, Germany, Luxemburg, France, Netherlands, UK	6,850	5,100	95
07-09.01.2005	Erwin	Denmark, Estonia, Germany, Latvia,	5,800	2,600	20

	(Gudrun)	Lithuania, Sweden, UK, Finland			
23-25.01.2009	Klaus	France, Spain, Italy	5,100	3,000	25
26-28.02.2010	Xynthia	France, Germany, Switzerland, Belgium, Spain, UK, Portugal, Netherlands	4,500	3,400	65
27-28.12.1999	Martin	France, Spain, Switzerland	4,100	2,500	30
15-16.10.1987	87J	France, Norway, Spain, UK	3,900	3,100	20
25-27.02.1990	Vivian	UK, Germany, France, Netherlands, Belgium, Austria, Norway	3,200	2,100	50
3-4.12.1999	Anatol	UK, Denmark, Sweden, Germany, Latvia, Lithuania, Russia, Poland	3,000	2,400	20

Geographic distribution

Scientists argue that severe thunderstorms and tornadoes are much more common in Europe than most Europeans realize (Brooks and Doswell 2001). The main reason, for why this amount has not so far been pulled attention, has been attributed to a reduced frequency for each individual country (Doswell 2003). Figure 17 provides a map of the 3424 severe weather events in 2007, reported by the European Severe Weather Database (ESWD).

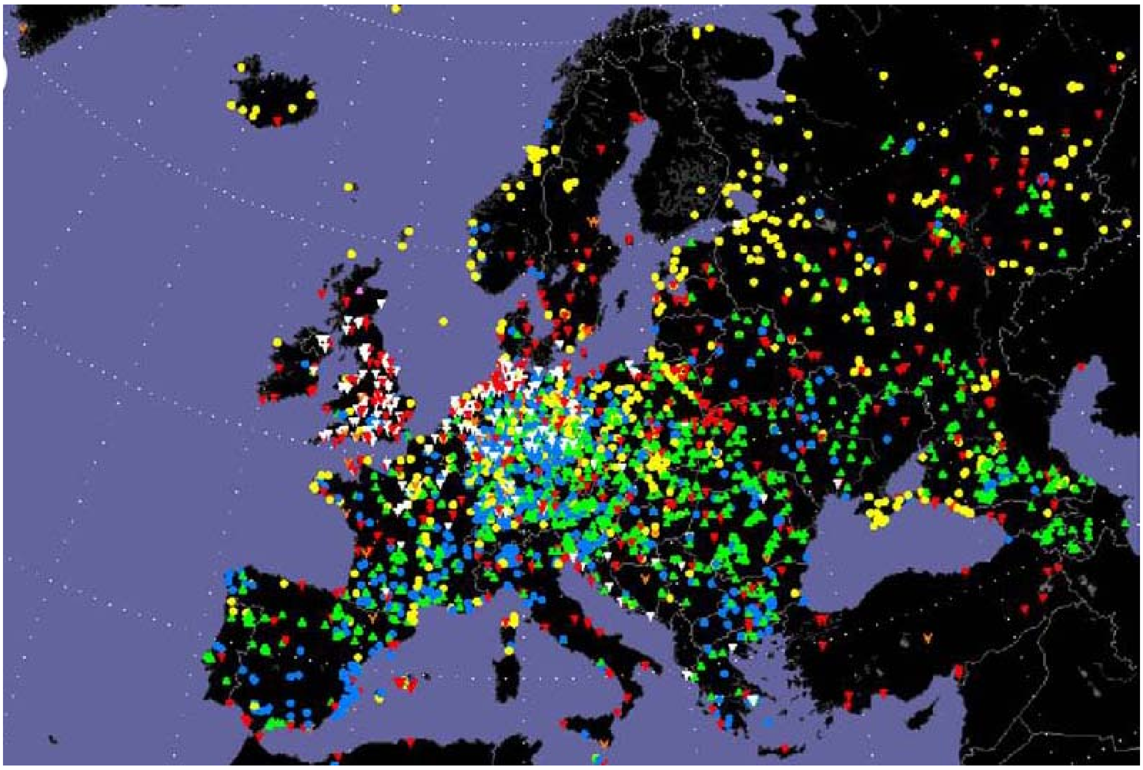

Figure 17. All ESWD reports for the year 2007 (n=3424).

Red: tornadoes, yellow: damaging wind, green: large hail, blue: heavy precipitation. Date of ESWD inquiry: 7 October 2008 (Dotzek et al. 2009).

Thunderstorms during the summer are a frequent and dangerous weather phenomenon in the central Europe and the Alpine region (Houze 1993, Hagen et al. 1999, Bertram 2000, Kann 2001).

Adaptation options

The main adaptation measure being taken by the majority of the European countries are the forecasting and early warning systems. Implementation of measures other than warning systems varies across countries, and is often not specialized for wind storms, but related to those on urban flooding.

Forecasting and early warning systems:

Warning the authorities and the public by forecasting severe weather events a few days or hours ahead of approaching storm events is crucial for emergency actions, such as the evacuation of buildings and transport of the population to storms shelters to be taken. According to Rauhala and Schultz (2009), National Hydro Meteorological Services (NHMSs) in 28 European countries operate forecasts for severe thunderstorms, damaging wind gusts, large hail and tornados. 23 countries offer early warnings based on the forecasts.

Apart from these technology based systems, information is disseminated also otherwise: Hungary and Germany utilize spotter groups[18], supporting the meteorologist services with weather reports operationally. The Finnish Meteorological Institute (FMI) receives weather-related emergency reports directly from the Emergency Response Centres. The prompt dissemination of information is as important as forecasting extreme weather events, as communication with the authorities, public and media can save several lives. Usually, NHMSs share the information on their web pages. In some countries, the dissemination of information is the responsibility of civil protection authorities. Also text messages to mobile phones are used as warning system, e.g. in Germany and the Netherlands. In Finland, it is an obligation to make immediate announcement in the media, in case extreme weather events are recognised.

The exchange of warning information in Europe has become easier since utilization of web based systems, such as:

- Meteoalarm (operational since 2007), where the European weather warnings from EUMETNET countries are displayed (www.meteoalarm.eu),
- The European Severe Weather Database (operational since 2006), a web based interface where the public and NHMSs can submit and retrieve severe weather reports (ESWD, http://essl.org/ESWD/), and
- The European Centre for Medium-Range Weather Forecasts (ECMWF), providing three to 15 day weather forecasts to its Member States and Co-operating States to provide early warnings to civil protection agencies and the general public.

Stormwater Treatment:

The increasing interest in stormwater pollution, combined with the expansion of European cities and the existence of old drainage systems, led many European countries to adopt source control techniques for storm water treatment in national initiatives (Saget et al. 1995). Source control techniques are particularly attractive for stormwater treatment, as they are decreased in costs compared to massive end-of-pipe

[18] A storm spotter actively maintains the development and progression of specific weather events while actively relaying important information to the local weather agency in a timely manner.

treatment installations. They reduce the overall stormwater flooding and permit the expansion of cities without requesting reconstruction of the existing sewer networks. Different policy instruments (taxes, specific regulations and controls, information campaigns) have been applied in order to promote source control techniques. For example in Dresden, the water company collects taxes based on the imperviousness of properties. Additionally, Dresden reuses rainwater for municipal use and has organized public campaigns for the promotion of source control techniques (Chouli et al. 2007). The Netherlands national policy aimed at reducing 50% of the combined sewer overflow until 2005. Municipalities and industries pay fees to the Water Boards, depending on emitted pollution in waste water. The application of this policy forced many municipalities to construct new waste water treatment plants with the capacity to treat both wastewater and storm water. Some municipalities chose to implement, in parallel, the disconnection of the storm water from the sewer network. These projects have been proven successful. A new national policy prescribes the disconnection of 20% of the existing urban areas from the sewer network. Municipalities organize public information campaigns, offer technical guidance and financial help (e.g. 5 €/m² of disconnected surface in Nijmegen, NL) to house owners that want to disconnect (Förster et al. 2004).

The city of Stockholm, as well as several municipalities in Denmark, presently plans to implement source control techniques to all new sewage projects. North Rhine-Westphalia, Germany, demands the infiltration of storm water into all new development projects and offers funding to municipalities (Förster et al. 2004).

However, the application of source control techniques across Europe is just beginning and techniques are still in an experimental phase (Chouli et al. 2007).

Insurance:

Insurance has long been an effective instrument to manage climate-related risks and will play an important role in adapting communities to climate change. Financing the repair or replacement of structures that suffer infrequent, unforeseeable losses can increase the adaptive capacity of the society. Several European insurance companies have already included climate change driven wind storms into their insurance portfolio, such as Munich Re in Germany. However, mainstreaming activities across Europe are not feasible, yet.

Awareness Raising, Capacity Building and Training:

Awareness raising, capacity building and training are important tools when adapting to the impacts of extreme weather events are concerned. The UK Climate Impacts Programme provides climate projections (termed climate scenarios on that site), as well as an adaptation wizard to help users to work their way through potential vulnerabilities and methodologies to appraise options and make decisions (http://www.ukcip.org.uk). Adaptation projects on storm surges across Europe are, however, not very concrete but still in planning phase.

Designing, Building and Retrofitting of Wind Resistant Structures:

Designing and constructing buildings and other infrastructure to resist wind in risk-prone areas is a key adaptation measure. However, there are no significant policies or measures to increase wind storm resistance of existing structures. At time of writing, no concrete implementation for adaptation measures against storms across Europe are known.

Decentralized energy sources:

The decentralized energy supply based on renewable energies is increasingly recognized as suitably adapted to climate extremes and black-outs compared to large centralised power plants. In the City of Altötting, Austria, more than two thirds of homes are now heated with biomass fuel, heat pumps, and local and central district heating, after floods caused inundation of heating fuel tanks and contamination of water.

Building codes:

Involvement of storm resistance to all building codes can decrease the losses from wind storms. However, no such European wide measures seem to exists, apart from the building codes for bridges.

In summary, adaptation to wind storms is a new concept in Europe. Only the common impacts with other extreme events have been addressed to some extend, such as urban and coastal flooding. Wind storm specific impacts, such as damages in buildings and forests have not yet been studied well enough in Europe to drive clear adaptation plans and implement projects. Therefore, apart from early warning, forecasting systems and insurance tools, concrete projects in the urban areas to increase resilience to such events are scarce. It is not yet possible to analyze existing adaptation measures or to assess and compare their success with other adaptation options.

Barriers and drivers

The biggest driver for national governments to take adaptive measures for cities is the recognition of the potential damage and loss caused by big wind storms, which are projected to increase in frequency and intensity in Europe. Also, the damage that wind storms cause in the urban regions creates a bigger drive for local level adaptation measures, rather than the established national policies.

However, several European countries are still in need of more and better forecasting tools and expert knowledge, and many of them lack local research to support forecasting (Rauhala and Schultz 2009). Setting up a warning system for severe thunderstorms and tornadoes is considered to be complicated (Rauhala and Schultz 2009), since fore- and nowcasting require special knowledge and tools. This barrier is further challenged by the communication of nowcasting and warnings to the emergency-management authorities, media and public within the short time scales, upon which severe weather occur. An effective warning process also requires the verification of any severe weather occurrences from ground-truth[19] observations, which in some cases may be falsely classified as severe storm (Dotzek et al. 2009). Given that the public is inertial, it needs consistent warning information from multiple reliable sources (Mileti and Sorensen 1990); a single message reaching the public may not be able to initiate a response.

[19] Ground truth is a term which refers to information that is collected "on location". In remote sensing, this is especially important in order to relate image data to real features and materials on the ground. The collection of ground-truth data enables calibration of remote-sensing data, and aids in the interpretation and analysis of what is being sensed.

6.5 Cities and urban regions at the coast, facing sea level rise, storm surges, and saltwater intrusion

Particular threats

Storms and wind-driven waves are the primary threat to many European coasts. Wind speeds and storm intensities are projected to decline in the Mediterranean, but to increase in the north-eastern Atlantic and, locally, in parts of the Adriatic, Aegean and Black Seas until 2030 (IPCC 2007). There is also a probability for fewer storm surges in the Baltic area and southern North Sea by the 2080s (IPCC 2007). However, future storms are generally likely to be more extreme with higher wave heights, leading to erosion and flooding. Manly estuaries, river deltas and embayment, where cities are preferentially situated, are vulnerable.

Models using IPCC SRES scenarios project a global mean sea level rise of 0.09m to 0.88m by 2100, with regional influenced in Europe possible resulting in sea level rise being up to 50% higher than these estimates. The impact of the North Atlantic Oscillation (NAO[20]) and melting of Arctic ice and Alpine Glaciers adds additional uncertainty to these figures (IPCC 2007). Sea-level rise is likely to cause severe flooding, land loss, destruction of buildings and infrastructure, and salinisation of groundwater on Europe's coasts. The degree to which coastal regions and cities will be affected by sea level change is dependent on a large number of (yet unknown) parameters like for example flood protection measures, adaptive capacity and economic resources (Box V).

> **Box V BBC News: 9 Nov 2007**
>
> Thousands of people were told to leave their homes along the south-eastern coast of England on Thursday night in preparation for a predicted peak surge of up to 3m (10ft).
>
> The UK Environment Agency DEFRA warned of "extreme danger to life and property" in parts of Norfolk, Suffolk, Kent and Essex and issued eight severe flood alerts. The Met Office meanwhile warned of gusts of up to 145km/h (90mph) for the Orkney and Shetland islands in Scotland.

Large areas of the Mediterranean coastline in Italy, Spain and Turkey have been reported to be already affected by saltwater intrusion (EEA 2005). Also European islands, depended on water resources from coastal aquifers, are prone to salt water intrusion. Although overexploitation is the main reason for salt water intrusion, sea level rise can increase saltwater intrusion into the aquifers and a subsequent decline in water quality (Darnault and Godinez 2008). Coastal flooding due to sea-level rise could annually affect areas with high population densities in the southern North Sea and coastal plains and deltas of the Mediterranean and Black Sea by the 2080s (IPCC 2007). Approximately 20% of existing coastal wetlands may also get lost. Although the degree of coastal erosion resulting from sea-level rise is very uncertain, adaptation strategies for low-lying coasts will have to address sediment loss from marshes, beaches and dunes.

A future acceleration of sea level rise would directly increase the vulnerability of the following systems (key messages on vulnerabilities from ETC-ACC's coastal IVA review (ETC-ACC 2010)):

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[20] The North Atlantic Oscillation (NAO) influences coastal climates, winter wind speeds and patterns of storminess and coastal flooding in north-west Europe. The NAO also has a strong influence on sea surface height and the geographic distribution of sea-level rise on Europe's Atlantic coasts.

Baltic Sea: many large cities (e.g. Helsinki in Finland or Klaipeda in Lithuania) on the coast are already subject to changes in the occurrence of floods (river floods as well as storm surges) and sea level rise, decreasing water availability and quality (BaltCICA Project, http://www.baltcica.org). This will be enhanced.

Celtic Saes: Flooding from climate change is expected to become worse on the urbanised east coast of Ireland, especially the three major cities of Dublin, Cork and Galway are affected (Sweeney et al. 2003).

Macaronesian region: Higher sea levels will increase the risk of salt water intrusion into coastal aquifers and put the water availability at risk. No specific cities are mentioned.

Mediterranean Sea: A number of commercial fishing ports and fixed marinas are threatened, and a number of beaches may be destroyed or become submerged. Historical centres of coastal towns in Croatia, Zadar, Trogir, Split, Dubrovnik, Stari Grad and many others are just one or two metres above present sea-levels and could become prone to flooding. Additional, recreational areas along the Croatian Adriatic Sea and Greek Ionian Sea may be threatened by erosion and/or beach flooding, indirectly effecting nature services to human health and well being.

Black Sea: The Black Sea's coastal areas are expected to become increasingly vulnerable to the effects of erosion, partly due to climate change and sea-level rise, but largely due to the lack of effective coastal planning regulations. For example Turkish cities particularly in the Cukurove Delta, Antalya, Izmir, Istanbul and Samsun, where the coast is most highly populated, are highly vulnerable towards climate change (Kuleli 2008).

Particular sensitivity and vulnerabilities

Sensitivity and vulnerabilities to the effects of climate change in European coastal regions have significant regional differences because of differences in coastal environment. Differences in geological, oceanographic and biological processes can lead to substantially different impacts on a single coastal system at different locations.

Vulnerable areas

Key vulnerable areas along all marine basins in Europe include low-lying areas, especially deltas, lagoons, and tidelands. Particularly islands are vulnerable to sea-level rise, storms, floods and partly to a lack of effective coastal planning regulations. These low-lying areas are often close to key urban and economic areas, where major European cities and therefore major populations are located. For example the highly populated and economically important low-lying coasts of the Greater North Sea are particularly at risk from higher water levels and storm surges (EC 2009c). This includes more than 85% of the Dutch and Belgian coastline and the cities of London, Hamburg, Rotterdam and Antwerp.

Particular Sensitivity

Adaptation on the coast will be determined by constraints on adaptive capacity (IPCC 2007). Increasing numbers of people and assets on the coast are at risk from climate change and subject to additional stresses due to land-use and hydrological changes in catchments. Populated deltas and low-lying coastal urban areas are key societal hotspots of coastal vulnerability. An increasing population and a subsequent increase of economical capital (industry, properties, infrastructure, etc.) lead to higher sensitivity of coastal urban areas towards sea level rise and storm surges.

Sea-level rise has substantial inertia and will continue for many centuries beyond 2100. Settlement patterns also have inherent inertia, which presents challenges for long-term coastal planning. Since implementation of a coastal protection infrastructure in/around vulnerable parts of cities has a lead time of 30 years or more (OECD 2007) and will in many cases disrupt current settlement patterns, its sensitivity is strongly related to the quality and effectiveness of the cities spatial development plans and the commitment and financial means of local leadership.

Geographic distribution

Low-lying delta areas, especially the populated urbanized areas in the Southern North Sea, the Mediterranean and the Black Sea are vulnerable for sea-level rise and storm surges. A projected increase in wind speed in the north-eastern Atlantic (IPCC 2007) increases the exposure of the European west coast. Fewer but more extreme storm surges in the Baltic and North Sea, with higher wave heights, are likely to lead to increased erosion and flooding in estuaries, deltas and embayments there.

Salt intrusion is an issue for all European coastal areas that make use of coastal aquifers. However, those that are already short of water during the summer, e.g. the Mediterranean and Black Sea, are most vulnerable. The geographic distribution of vulnerability of coastal areas to climate change can only be discussed in fairly general terms due to a lack of (comparative) vulnerability research.

Adaptation options

The challenge for states across Europe is to harmonize national adaptation policies with regional spatial planning policies. The focus will need to be on the development of more robust systems. This includes technical solutions and improved control and risk management systems, combined with improved spatial planning.

There are three basic strategies to reduce society's vulnerability to events related to sea level rise, and for each strategy a range of adaptation options is available (Bijlsma et al. 1996, IPCC 1990, Klein et al. 2001). The three basic strategies are as follows:

1. *“Protect” to reduce the risk of the event by decreasing its probability of occurrence.*

To protect against the effects of sea level rise upgrading the coastal defenses to a higher level is the most common adaptation option, especially in low-lying areas in the North Sea and the Mediterranean. High priority adaptation options (based on importance, urgency, no-regret, co-benefits and mitigation) in the Netherlands (de Bruin et al. 2007) include integrated coastal zone management, more space for water, risk management as basic strategy and new institutional alliances. More specific options are dependent on factors like coastal morphology, exposure and characteristics of the (urban) region behind the coastal defences.

Available options can be divided in structural or hard engineering options and soft engineering options. Hard engineering includes concrete seawalls, rock armor, groynes and other permanent concrete or rock constructions. These ‘hard’ adaptation options are chosen when natural defences are weak or non-existent or space is limited. The latter is often the case around cities and so hard engineering prevails in many European cities. When the natural coastal structures like dunes prove to be sufficient the cheaper option is sand nourishment. Sand nourishment has many forms and has effects on the sandy beaches and dunes or on the shorebreakes a little out on sea in the case of sand-suppletion. The latter is popular at the North Sea coast because of relatively low costs. The European coast is very diverse in morphology and chosen a wide variety of coastal defence measures.

The extent to which cities should protect their coastal defences can be derived from the exposure to coastal erosion (see Figure 18). The coastal cities in for example Southern France, Belgium, Denmark and Estonia have a very high exposure to coastal erosion.

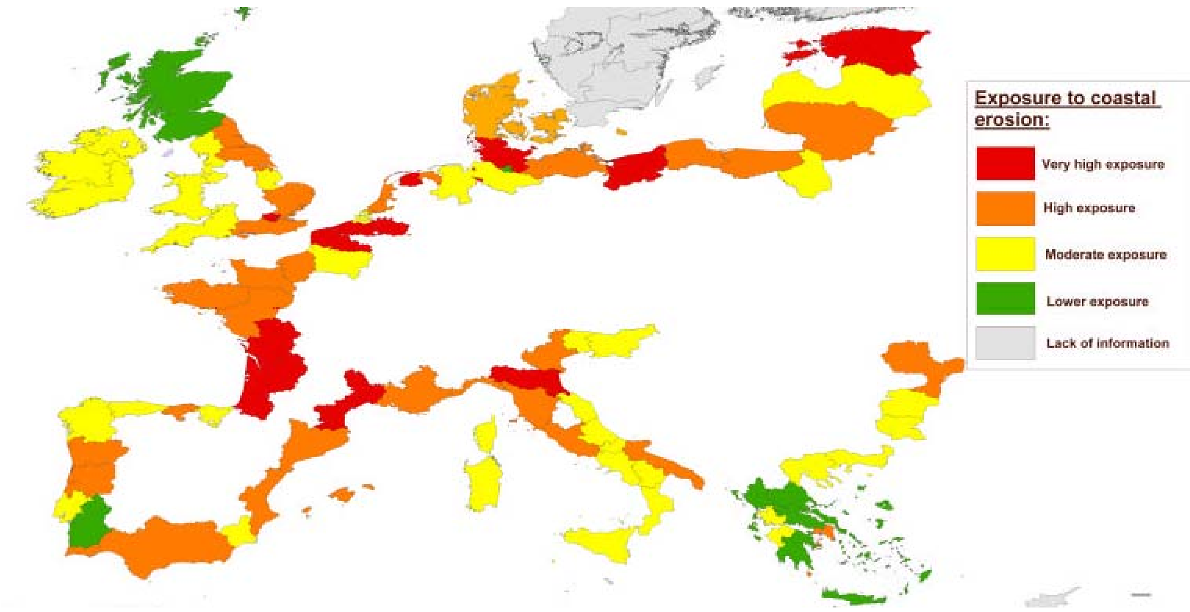


Figure 18. Exposure to coastal erosion.
Data source: Eurosion (EC 2004).

A wide variety of cities like for example Rotterdam, Alicante and Ostend will have to protect their coasts using one or more of the above options.

2. "Retreat" to reduce the risk of the event by limiting its potential effects.

For cities and urban areas at the coast the 'retreat' option is often not an option. If possible, adaptation options include more space for water to create a more dynamic coast. For urban areas, however, space tend to be limited, and also a certain amount of land will be lost in the process, destroying settlements and property making this option socially not very acceptable. This adaptation option has been implemented in for example Tollesbury and Freiston Shore (UK). The retreat and giving up land was part of a managed retreat plan to reduce the risk of flooding and a risk based allocation policy (de Bruin 2007).

3. "Accommodate" to increase society's ability to cope with the effects of the event.

Floods and storm surges have such a large impact on cities and societies that accommodation is only an option in a few cases. The adaptation option would be to make existing and new cities robust against the effects of these impacts by 'accommodating' the surplus of water in such a way that impact decreases. For example the City of Venice has constructed a storm water drainage in order to drain the city efficiently after flooding. The government assists the inhabitants in reducing the likelihood of flood through information and an early warning system.

Barriers and drivers

Historic climate conditions at the coast are diverse throughout Europe and coastal dynamics differ across

Europe. Barriers and drivers concerned with the coastal adaptation processes are, however, often related to land use planning, ecosystem protection approaches and other institutional arrangements.

Rapid population growth in coastal areas is leading to higher risks and thus coastal communities and cities will have to face the challenge to protect, redesign or relocate in the future. One major barrier to this is the prevalence of short term strategies. The often expensive measures will be felt directly while the benefits might only come after the tenure of elected governments, elected officials and city spatial planners. Adaptation is one of the conflicting priorities is the political process.

Another barrier arises from ecosystem approaches and the spatial conflict between coastal ecosystem reserves and urban planning and protection. Especially low lying delta areas with lagoons or tidal inlets tend to have prevalence for static coastal defense structures, conflicting with the dynamics of most ecosystems.

Box VI Storm Water management

The Netherlands are discussing new arrangements and possible measures to make the primarily low lying delta climate proof for the years to come. One plan, involving numerous stakeholders, is to close the "Nieuwe Waterweg", an open but regulated gate way to the North Sea. To defend the inland urbanized areas against flooding by sea level rise, to prevent salinisation and to ensure water availability, it would be best to permanently close the regulated gate way. However, this measure would be devastating for the inland salt water ecology.

Solving the problem of such complex water management with many influencing stakeholders can be regarded a barrier in the development of the Dutch coast (Directorate General of Public Works and Water Management, 2010). The discussion of this issue has started and is expected to last a long time due to a myriad of stakeholders involved.

Drivers to coastal adaptation are local communities, supported by their local governments and their inhabitants. Other important (but conflicting) stakeholders are environmental organizations, harbour-industries, recreation organizations and many more.

6.6 Cities and urban regions in the Alpine region facing natural hazards

The European Alps form the largest mountain range in central Europe covering some 192,000km2 of land area and stretching over 1,200 km from Austria and Slovenia in the east, through Italy, Switzerland, Liechtenstein and Germany to France in the west. They are among the world’s most densely populated mountain regions. Nearly two-thirds of the population in the European Alps (which totals 14.2 million) lives in towns or periurban municipalities. Compared to large metropolitan areas on the perialpine edges at the foot of the mountains on both sides of the Alps, towns in the mountains have remained small or medium-size centres for the most part. Seven major towns (Grenoble, Salzburg, Maribor, Innsbruck, Trento, Bolzano, Klagenfurt) with populations of 90,000–150,000 stand in contrast to a large number (232) of small and medium-sized towns, that is, municipalities with at least 10,000 inhabitants or 5000 jobs. As political and economic centers, Alpine agglomerations have the capacity and responsibility to influence development strategies for the Alpine arc (Perlik 2001; see also Figure 19).

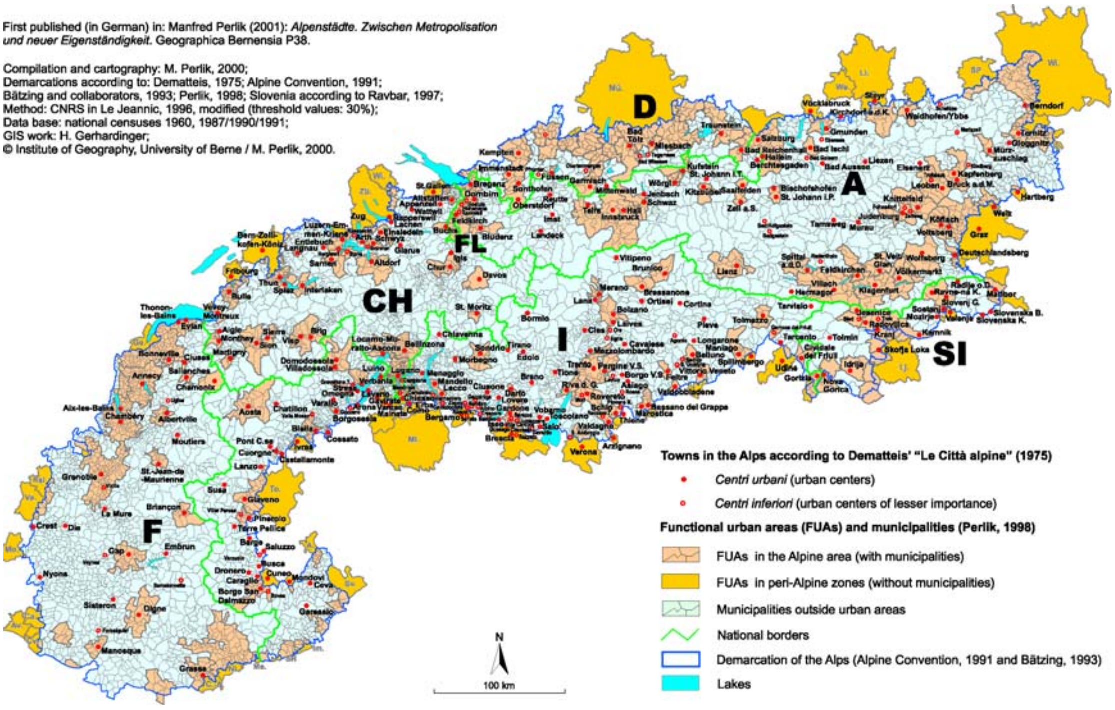


Figure 19. Changes in urbanization patterns in the Alps between 1960 and 1990.

Central places were identified by Dematteis according to criteria defined in 1960 (*Le Città alpine* 1975).

Particular threats

Natural hazards are inherent to Alpine countries and have significant impact on Alpine societies and economies, generating economic losses of EUR 57 billion over the 1982-2005 period. These hazards are highly influenced by natural and climatic factors such as precipitation, temperature, slopes and biomass cover. Consequently, these hazards are sensitive, at various degrees, to climatic changes (OECD 2006). Extreme events, by definition, are rare, but in a changing climate their frequency and/or intensity may alter (Van der Linden and Mitchell 2009, ENSEMBLES Project).

As climate change is expected to transform the nature of hazards, Alpine cities and urban areas will be faced with a number of threats that are in general not different from the ones affecting cities in other geographic regions in Europe, namely storms, flooding, heat-waves and droughts. In the following only those threats are highlighted that are specific for cities and urban areas in the Alpine arc.

Out of all natural hazards affecting the Alpine region, in particular storms, floods and forest fires are expected to impact densely populated areas. In return, avalanches, mass movements and effects of glacier and permafrost retreat will rather affect high mountain ranges and likely only result in indirect impacts for cities and urban areas in the lowlands (see Table 14; OECD (Wengen Workshop) 2006). Thus, it appears that one has to differentiate between natural hazards mostly threatening smaller communities in higher elevations of the Alps (e.g. avalanches, rockfalls) from those relevant for cities in the lowlands (e.g. storms, floods, forest fires).

Table 14. Climate change impacts on natural hazards in the Alpine Arc;

(This table was establish based on information presented in previous sections or provided by experts present at the OECD-Wengen 2006 Workshop on “Adaptation to Climate change in the European Alps”)

Changes in Natural Hazards	Confidence in projected changes	Most affected regions	Economic importance
Permafrost related hazards: Increase in frequency of rockfalls and magnitude of debris flows	Very high	High mountain range, tourism areas	Low
GLOFs: increasing incidence of Glacial Lake Outburst Floods	Very high	High mountain range, tourism areas	Low
Other Glacier related hazards: Increasing frequency and magnitude	High	High mountain range, tourism areas	Low
Winter Floods: Greater intensity and frequency	Medium	Lower mountain range, densely populated areas	Very high
Storms: Greater intensity and frequency	Medium	Alpine arc, densely populated areas	Very high
Rockfalls: Increasing frequency	Medium	Lower to medium mountain range	Medium
Forest fires: Increasing number of events in Southern Alps	Medium	Lower mountain range of Southern Alps	Medium
Landslides and debris flows: Increasing frequency and magnitude	Medium/Low	Lower to medium mountain range	Medium
Avalanches: Increasing frequency and magnitude at high altitudes	Low	High mountain range, tourism areas	Medium

One specific phenomenon in different Alpine regions is Foehn (see also Box VII), a down slope wind that is strong, warm, and very dry. Although in some areas foehn winds are positively influencing agricultural possibilities, they mainly negatively affect air quality, fires, traffic accidents, and human health (e.g. migraine) (Richner and Hächler 2008). According to the Swiss National Platform for Natural Hazards (PLANAT[21]) the potential and intensity of foehn is expected to increase due to the green house effect raising the energy and water content of the atmosphere.

Forest fires are affecting cities both directly and indirectly (e.g. smoke plumes significantly degrading air quality, exceedances of 24-hour PM10 and PM2.5[22] standards). Their occurrence is largely determined by climatic variables, such as high temperatures, droughts, winds (foehn), and thunderstorms. Increasing trends have already been observed in some Alpine regions. Reinhard et al. (2005) showed that fire risk due to drought events increased over the 1971-2005 period in southern Swiss Alps. Under climate change conditions, expected temperature increase and potential increase in heavy winds (in particular foehn) and droughts would create more favorable fire conditions especially in the Southern Alps (OcCC 2003).

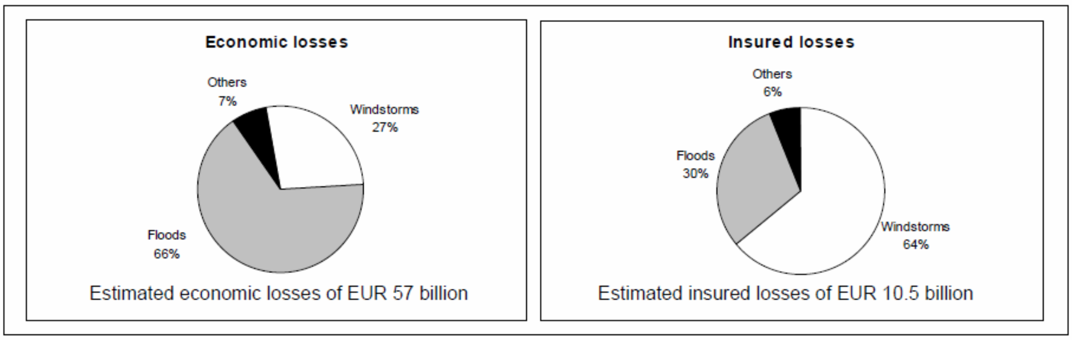
Another most relevant threat for Alpine cities is the projected facilitation of the hydrological cycle in the Alps (under all IPCC 2007 scenarios). This implies serious consequences for water circulation and water management in the Alps: rainfall would decrease in summer and increase or become more intense in

[21] PLANAT, Swiss National Platform for Natural Hazards; Information on Climate change and natural hazards, http://www.planat.ch/index.php?userhash=132790213&nav=4,476,476,476&l=e

[22] The notation PM10 and PM2,5 describe fine particles of 10 and 2,5 micrometers or less in aerodynamic diameter. Particulate pollution is associated with some 200,000 deaths per year in Europe and other health problems, including asthma, lung cancer and cardiovascular issues. Due to the health effects of particulate matter, the EU has set limits for PM10 in the air (1999/30/EC and 96/62/EC on ambient air quality assessment and management).

winter. In addition, the snow line would rise by 200 meters by 2050 and glaciers would continue to melt. Accordingly, floods in medium and low-lying regions would increase both in intensity and in frequency during winter (Bogataj 2007).

Of all hazards in the Alpine regions, floods are creating the most economic damages (see Figure 20), and many of the most densely populated Alpine areas have been hit severely by floods in recent years (e.g. Austria, Germany and Switzerland in 2003 and 2005).



Source : Data provided by MunichRe, GeoRisk Research © 01/2006 NatCatSERVICE ®.

Figure 20. Economic and insured losses due to natural hazards in the Alps 1980-2005 (OECD 2006).

Allamano et al. (2009) show that global warming increases flood risk significantly. The researchers found that large floods have occurred more frequently in recent years than in the past, and they predict an increasing trend due to global warming in the future.
With regard to heat waves the biggest impacts are rather to be expected in high-altitude areas, where melting of glaciers and permafrost trigger e.g. avalanches and setting off more rockfalls. This poses a hazard to mountain communities rather than for cities and urban areas in the lowlands (Keiler et al. 2010). In many Alpine countries though, particularly in France, the big heat wave in 2003 was associated with an increase in mortality, especially in cities. For Switzerland excess mortality was limited to the region north of the Alps, e.g. Basel, Geneva and Lausanne. Increased mortality in urban centres has been attributed to the urban heat island effect (Grize et al. 2005).

Particular sensitivity and vulnerabilities

In the Alps, the percentage of land that can be settled permanently is very limited due to the natural landscape and the threat of natural hazards. The higher risk as a consequence of climate change is capable of restricting the space available for permanent settlement even further (CIPRA 2010).

However, with ongoing population growth, economic development, and urban sprawl and very few extreme events causing severe damage from the early to the late 20th century, developed building land has continuously expanded to risk exposed areas (CIPRA 2010). Accordingly, e.g. in Switzerland, the damage potential of floods, mudflows, landslides or winter storms has become much larger (FOEN 2009).

An increase of precipitation during winter causes a regional and seasonal shift of drainage. This and the occurrence of flash floods will challenge the design capacity of water collection systems in cities and urban areas and thus multiply the probability of flooding, posing similar problems than in every other city across Europe (see section 6.2.). Cities and municipalities in the Alpine Region are usually in charge of their water supply, which is delivered by thousands of local and (supra-) regional water companies in a decentralized manner (EEA 2009d). This implies an even higher vulnerability to potential contamination.

Alpine cities are particularly affected by foehn events. Foehn air can easily triple existing ozone concentrations by subsiding air from high altitudes with high natural ozone concentrations (Baumann et al. 2001). Foehn winds are also capable of redistributing pollutants which are emitted, e.g., by combustion processes near the valley floor even in very thermally stable wintertime conditions (Gohm et al. 2006). Even though Alpine cities and urban regions mostly show good air quality, foehn storm events can promote pollution burdens in the short term.

The most striking danger of foehn for settlements is, however, the spreading of fires caused by warm and very dry air combined with high wind speed. In the course of time, numerous towns burned down completely. In 1861, 600 houses of the capital city Glarus (CH) were completely devastated during a foehn storm, and only recently, in 2001, a fire maintained by foehn winds in excess of 15 m/s destroyed 15 houses in Balzers (Principality of Liechtenstein).

Box VII Foehn winds are also dangerous to flying, example Innsbruck (A)

The city of Innsbruck is situated at the height of 574 meters down in the narrow valley of Inn River and is called the “foehn capital” of the Alps. Innsbruck´s airport is well-known in the aviation world for its demanding approach due to the surrounding high peaks of the Alps and the unique weather, in particular the probability of foehn events. Therefore certain aircraft types are prohibited from operating at the airport, others need to obtain special authorization given by the state authority in charge with air traffic control and safety of Austrian airspace, Austro Control GmbH. During south foehn conditions the approach and departure zones of Innsbruck airport are affected by turbulence and wind shear. These are caused by lee effects, low level jets, and hydraulic jump phenomena. Pilots landing at Innsbruck airport have to hold a special education to handle these unique conditions.

With regard to the anticipated increasing risk of forest fires a relatively little amount of fire of small extension has strong effects on human safety and mountain economy with widespread erosion, loss of soil and possible triggers of landslides, which can cut off roads affecting infrastructure networks with supply functions for cities. Wildfires also have an important impact on air pollution also with consequences for human health and on the greenhouse gases balance[23].

Urban areas typically experience higher night temperatures than surrounding suburban or rural areas, because heat is retained more efficiently in densely built urban areas. Grize et al. (2005) showed for Switzerland that excess mortality caused by the heat wave in 2003 occurred particularly in urban centres and suburban areas, whereas in rural areas only the August heat wave was associated with a significant increase in mortality. Similar patterns of heat related mortality have been observed in France.

Geographic distribution

The Alpine arc covers an area of about 190.000 square kilometers, and is home to about 15 million people. Most of the population is concentrated in low-lying valleys which are often very densely populated (OECD 2006). The Alpine arc comprises the territory of seven countries, 83 regions and about 6,200 communities.

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[23] ALP FFIRS, Alpine Forest Fires Warning System; project co-funded by the EU INTERREG Alpine Space 2007-2013 Programme under the priority 3 “Environment and risk prevention”, http://www.alpffirs.eu.

In terms of population distribution, the Alpine region is undergoing a process of urban growth and rural exodus. Rapid growth is to be observed in both the main urban centres and the low-altitude locations in the mountain valleys, while the small communities in the mountains proper are shrinking at a growing rate.

Most people in the Alps live in cities (58%) where the majority of jobs are found (66%). A few cities within the Alps are growing along the broader valleys in a linear pattern. They are well connected to large cities outside the Alps. Additionally, adjacent metropolitan areas (e.g. Munich, Vienna, Zurich, Milan) are sprawling into the Alps (WWF 2005).

The Alps are characterised by considerable spatial variation in climate, and their physiography plays a key role in determining rainfall and temperature. With regard to precipitation, an east-west gradient is observed in the Alps, with less precipitation in eastern Switzerland and Austria than in the western Alps which are exposed to moisture from the Atlantic. However, the seasonality of rainfall is much more spatially variable and dependent on location and orthography (Frei and Schär 1998). Valley bottoms are generally warmer and drier than surrounding mountains. Temperature inversions are common during fall and winter up to a height of about 1.000 meters. In terms of seasonality, temperatures across the Alps exhibit a peak during the summer months.

Foehn blows down from the crest of the Alps mostly from a southeasterly, southerly, or less frequently, from south-westerly direction. Dramatic temperature rises that reach 10°C and occasionally even 20°C or more - sometimes in a matter of minutes - are especially caused by south foehn, which blows from northern Italy, where the air is warm, to the north of the Alps (Austria, Germany, Switzerland). Due to the higher exposure of valleys that trend S.E.-N.W. or S.-N., the district of most frequent occurrence is between Geneva and Salzburg, immediately adjoining the main chain of the Alps to the south (Von Hann 2009).

For forest fires, the lower mountain ranges within the Southern Alps are the most affected regions due to climatic and environmental factors (FAO 2001, OcCC 2003).

Adaptation options

Alpine countries have always been exposed to the threats of natural hazards. Strategies to prevent or to reduce the effects of natural hazards such as flash floods, debris flows, landslides, rock falls and avalanches in areas of settlements and economic activities have a long tradition (Holub and Hübl 2008). In order to manage these events, a variety of economic, legal and technical tools are in place. The OECD concludes that in the Alpine Arc, the current frameworks have the ability to successfully manage natural hazards damages (OECD 2006) under current and future circumstances.

Nevertheless, some initial adaptation measures have been put in place recently but generally as a response to past extreme events rather than under the headline of climate change adaptation. For example, as response to the hot summer in 2003, the city of Lausanne has reviewed its municipal use plan ("Kommunaler Nutzungsplan") for opportunities to create new fresh air corridors, reduce sealing and maintain green areas and forests (Forum Raumentwicklung 2009).

Based on desk research and telephone interviews with selected key experts from Austria, Italy, Switzerland and Germany, we could not identify any adaptation measures in Alpine cities which have been planned and implemented pro-actively as a response to future climate change.

In recent years it was mainly due to flood disasters that regional planning laws were amended and hazard zone plans have become a more or less a binding standard in building land zoning processes (e.g.

Switzerland, South Tyrol/Alto Adige, Bavaria, Upper Austria; CIPRA, 2010). In contrast, municipalities located at higher altitudes (e.g. Engadin, Berner Oberland, Grindelwald) are already facing problems caused by climate change, e.g. melting of permafrost and glaciers causing landslides and soil instability and thus are putting adaptation measures in place. For example, in the case of Grindelwald (located on 1.050 m), two protection dykes were built to catch 240.000 m³ of bed load.

In the past, protection against mass movements and avalanches has been mainly organised by implementing permanent measures in the upper parts of the river catchments and in the release areas of avalanches (Holub and Hübl 2008). These measures were supplemented by silvicultural efforts to afforest high altitudes. Forests in the Alps play an important role to protect cities and municipalities from rock fall, landslides etc. Climate change will influence the vitality of forests due to e.g. heat stress or new varmints. Thus, a decrease in forest stability will also lead to a decrease in protection function which might cause new problems in the future. For example, the draft version of the National Adaptation Strategy (NAS) for Switzerland highlights the importance of forests for the protection of municipalities and cities. Experts estimate that around 66.000 ha of forest might be negatively affected by a changing climate. Thus, the draft NAS has included an adaptation measure to secure the protection function of the forest. The aim is to regenerate the area with species in accordance with the location.

Hazard maps serve as a basis for integral risk management strategies. They are approved and implemented by the responsible authorities to 100 % of areas at risk in Austria, around 50 % in Switzerland and at least to 30 % areas in France (OECD 2006). Knowledge about events that have occurred in the past, as well as an analysis of at-risk areas from both the landscape and engineering perspectives is indispensable in the prevention of natural hazards (PLANALP 2008). In order to prevent further risks, hazard maps must be factored in to spatial planning. Another important supplement would be to strengthen climate change considerations within the context of strategic environmental assessment, which applies to all plans and programs to be developed under a legal provision (e.g. zoning plans).

The Commission Internationale pour la Protection des Alpes (CIPRA 2010) foresees measures to be taken by spatial planning with respect to the following effects of climate change: (1) Dealing with new and aggravated climate-related natural hazards on the basis of hazard zone plans and hazard maps and (2) Prevention of heat islands in densely built-up core cities. Climate change as a risk factor requires a fundamentally new approach to hazard zone planning, as planning decisions can no longer be based on past experience only. Furthermore, due to long planning horizons any measures taken often become effective only decades later. Thus, it would be imperative to implement urban adaptation measures pro-actively to be already in place for preventing future damage due to natural hazards.

Cross-national cooperation networks at local to international levels, such as the Alpine Convention (2009), can assist in adapting to climate change by e.g. exchanging information and experience or initiating common projects (Box VIII).

Box VIII Example: Cross-national cooperation in the Alps

The Platform on Natural Hazards (called PLANALP) was set up in 2004 by the Ministers of the Contracting Parties of the Alpine Convention to develop common strategies designed to prevent natural hazards in the Alpine space as well as to deliberate on adaptation strategies. Main objectives of PLANALP are to discuss concepts for an integrated reduction of natural hazards, to identify “best practices”, to implement the subsequent measures and to intensify the cross-border exchange of experiences. Only recently, PLANALP has defined four priority action areas for prevention work against natural hazards in the Alpine countries, including climate change as one of the hotspots topic. The priority objective of a strategy to adapt to climate change must be at least to preserve the current level of residual risk and to take new and additional action on safety in terms of organisation, planning and construction, as necessary.

In summary, particular adaptation options in Alpine cities which have been planned and implemented pro-actively as a response to future climate change could not be identified. Activities on adaptation at a regulatory level include Alpine countries that have been implemented National Adaptation Strategies (NAS) (e.g. France, Germany) or are in the course of developing one (e.g. Austria, Switzerland). No information is available for Italy, Lichtenstein and Slovenia.

In the case of France, the NAS includes a paragraph about climate change in cities, but no focus was put on cities in mountainous regions. Further, a strategy for adaptation is available for the Rhone-Alps (Rhônalpénergie-Environnement, 2007). Nevertheless, also this strategy does not include city-specific information on adaptation. In Austria and Switzerland, the importance of climate change for cities will also be addressed. Both strategies can be expected in 2011.

Barriers and drivers

The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) is carrying out a study that, inter alia, assesses barriers and drivers in climate change adaptation for twelve Swiss cities[24]. Even though the results show the specific situation in Switzerland, interviews with seleced key experts from other Alpine countries undertaken for this scoping study draw a very similar picture. Thus, the outcomes can be taken as indicative for urban regions in the Alps.

The results from interviews with Swiss representatives from urban planning and environmental agencies demonstrate that the awareness for the need of adaptation to climate impacts in urban areas varies greatly (Forum Raumentwicklung 2009). In only a few urban planning and environmental agencies, the issue was discussed more or less intensely. For most cities, climate change adaptation is still a completely new topic. In contrast to climate mitigation, which poses a priority topic in almost every town, climate change adaptation is mainly not yet on the agenda.

A lack of knowledge about the effects of climate change specifically on urban regions can be seen as a major barrier to adaptation. For example, the city of Zurich is currently in the course of developing a climate change and impact analyses in cooperation with research institutes. This is regarded as the first step towards an adaptation action plan for the city of Zurich (Forum Raumentwicklung 2009). In addition,

[24] Study is part of the ESPON 2013 project: “Climate Change and Territorial Effects on Regions and Local Economies - Case Study Alpine Space”. First results are published in Forum Raumentwicklung, 2009.

city planners in Innsbruck are lacking relevant information on regional climate change effects. E.g. for urban heat island effects information on microclimatic conditions, fresh air corridors, exchange areas, etc. is missing. Furthermore, knowledge important for adaptation is largely not available (Umweltplan Innsbruck 2001).

Besides the lack of information on climate change impacts and adaptation, many respondents also mentioned unclear responsibilities due to the cross-sectoral and cross-level nature of adaptation and limited financial resources as obstacles to adaptation.

Another barrier on the way to urban climate adaptation is the long term time horizon of climate change impacts. Acute problems in urban policy (e.g. regarding transportation) are often given priority to act on rather than adaptation to climate change. This is mostly due to the fact that regional impacts are still difficult to project and are expected to become increasingly relevant only in 20-30 years.

In particular, spatial planning must play an essential role to put adaptation into practice. The role of spatial planning, the type of adaptation measures, and the mode of interaction with other sectors are currently being studied and discussed in research projects for the Alpine area. The Alpine Space project CLISP (Climate Change Adaptation by Spatial Planning) aims at preventing, reducing and mitigating climate-change related spatial conflicts, vulnerability of spatial development and spatial structures to adverse climate change impacts, and consequential damages and costs. It intends to contribute to sustainable, climate-proof spatial planning and territorial development in the Alpine Space. One of the main objectives is to develop and apply a transferable concept and methodology of regional spatial vulnerability assessment and providing knowledge of vulnerabilities in model regions.

6.7 Conclusions

Climate change adaptation in cities is at the starting point but very actively enhancing.

Technologies and expert knowledge are already available, but the synthesis of knowledge, awareness, commitment and investments to appropriately apply these ingredients for effective and efficient climate adaptation action is lacking behind. It will now be important to draw upon existing experiences, tie together different backgrounds and support emerging activities as much as possible in means of information and financial endorsements. Climate adaptation offers a large amount of economic opportunities and life quality options, such as innovative building and construction approaches and urban-ecological enhancements.

The call for action is urgent and the need to supply safe cities to an increasing amount of citizens demanding: The projections of the European urban sprawl show that by 2020 approximately 80% of European population will live in the urban areas and therefore be exposed to heat waves, urban flooding or water scarcity. Additionally, the urbanization process is accompanied by a spread of low density suburbs and industry into sensitive and ecologically valuable regions such as floodplains, groundwater recharge areas, fresh air corridors, protected habitats and unstable slopes. This is where adaptation has the chance to start from the scratch.

7 Appendix

7.1 Vulnerabilities and vulnerability indicators for urban regions

In this section, first the ways are described how different vulnerable systems will be affected by climate change and why they are vulnerable. How single vulnerable groups are affected by climate change is described in detail in section 3.2, thus it is not discussed here. It also contains some general vulnerability indicators for climate change related vulnerability as a whole. In the following sub-sections, threat specific vulnerabilities and identified vulnerability indicators are described in detail. There, the factors are discussed which determine why a specific urban system, a specific population group or the urban system as a whole is sensitive to specific climatic threats.

Information on components determining vulnerability and indicators available:

1. Urban vulnerability to climate change in general
2. Heat-related discomfort and mortality/morbidity
3. Decreased precipitation, water availability/water stress
4. Wild fires
5. Fluvial floods, flood claims and health effects of flooding
6. Intensive precipitation and urban drainage floods
7. Sea level rise and storm surge-driven flooding

Information on components determining vulnerability available:

8. Saltwater intrusion into aquifers
9. Wind storms, storm claims
10. Mass movements and erosion
11. Vector borne and other diseases

7.1.1 Urban vulnerability to climate change in general

Short descriptions on vulnerable urban systems

Energy supply system

Includes: all energy generating facilities and the infrastructure needed to make fuel available (e.g. coal, natural gas, biomass, etc), plus transmission lines/systems to make energy and heat available to end-users.

Reasons for vulnerability:

- Renewable energies generation depends on climatic conditions which are not predicable for the long term future.
- Thermal generation depends on availability of scarce fossil fuels and on water supply (for cooling equipment).
- Severe climate change conditions can affect ecosystems and reduce or exhaust their ability to generate fuel (e.g. biomass) for energy production.

- Fuel transportation to the power generating facility is subject to well-functioning infrastructure, with the related risk of infrastructure being damaged as a result of extreme weather events.
- Centralised energy generation can compromise energy supply to the territory during and after extreme events (compared to energy being generated in a more decentralised way).
- Climate change phenomena—both in terms of increasing temperatures/heat waves resulting in an increasing energy demand and in terms of storm/snowfall/etc causing damage to the system—can cause the overload and failure of power generating plants, triggering an overload-failure effect across the system and causing energy supply failures.
- Failures in the energy-supply system can have a cascading effect down to other systems that depend on energy supply, reducing or interrupting the services provided by those systems.
- Drought and other weather events (e.g. floods, extreme heat) can have a direct negative effect on crop and biofuel production.
- Floods and sea level rise can affect and cause power generating plants located near a riverbank or in a coastal area to fail.

Communication and information system

Includes: All channels that serve to convey messages to the population and the systems that support them (e.g. internet connections, newspaper printing facilities, systems built to warn the population of expected hazardous natural events: e.g. high tides or heat alert systems).

Reasons for vulnerability:

- Infrastructures may be subject to damage as a result of extreme weather events, or as a cascading effect from a failing energy-supply system with knock on effect on the regional economy

Transportation system

Includes: All roads, railways, waterways and airways that link a city or urban region to and from places beyond its boundaries and which are used for the transportation of people and goods.

Reasons for vulnerability:

- Increased temperatures pose a risk to the health of travellers and increase the demand of energy (e.g. increased use of air conditioning).
- Risk of accidents of travellers during extreme events is higher than under stable weather conditions. Accidents and extreme weather events can cause not only personal death/injury, but also interrupt the flow of transportation to and from urban areas.
- Increased pressure from extreme weather conditions may cause damage to transport infrastructures (e.g. melting asphalt, infrastructure heat buckling and destabilising, destruction by erosion, landslides, floods, or fallen trees after severe storm, etc) and potentially alienate residents during and after extreme events.
- Electrical pumps in gasoline stations may fail if there is an interruption in the energy-supply system (due to extreme weather events), affecting the motorised vehicle operation.

Water supply system

Includes: The areas in the territory where water is stored naturally (rivers, lakes, groundwater) and in man-made structures (reservoirs, water tanks and towers, rainwater collectors—water butts[25]), as well as the infrastructure necessary to bring it to the end-users at a usable quality, such as water treatment facilities, pumping stations, pipe networks, and connections to the sewer system.

Reasons for vulnerability:

- Higher temperatures increase evaporation of surface water bodies, reducing the availability of this resource.
- Higher temperatures also increase the demand of water by other systems (eg. cooling at thermal power plants, irrigation) and by people, increasing the pressure on the water supply systems.
- Higher water temperatures damages cold water ecosystems
- Higher water temperatures in reservoirs increase algal blooms resulting in higher water supply treatment costs.
- Below average winter temperatures causes damage to water supply pipes increasing the rate of leakage from the system.
- Intense precipitation causes the erosion of hillsides and river banks resulting in the deposit of sediment and debris into rivers, lakes and reservoirs with environmental consequences and increased water supply treatment costs.
- Flooding of water supply infrastructure such as treatment plants and pumping stations can interrupt water services and cause costly damage.
- Droughts can affect the ability of the system to deliver service to the territory as low flows in rivers and reduced rates of recharge for aquifers and reservoirs restrict the amount of water available for abstraction.
- Low groundwater levels and sea level rise expose aquifers to the risk of increased salinity.
- Low flows in rivers and reduced volumes in reservoirs caused by below average rainfall lead to higher concentrations of pollutants in the water affecting wildlife and the cost of water treatment for supply purposes.
- Lack of rainfall increases the water demand for the irrigation of crops, parks, gardens and playing fields adding pressure to water supply sources.

Sewage and drainage system

Includes: The system (pipes) to collect and transport the sewage and storm water to the sewage treatment plants, as well as the plants themselves and the natural water bodies into which treated effluent and storm water runoff is discharged.

Reasons for vulnerability:

- In combined sewer systems (where domestic and industrial waste is mixed with storm water) intense precipitation reduces the effectiveness of the wastewater treatment process and causes overflows from the system resulting in untreated sewage being discharged to the environment.

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[25] See an image of one: http://www.wheelchairdriver.com/images-car-valeting/water-butt-large.jpg

- Flooding of wastewater treatment works stops them from operating and causes the release of raw sewage to the environment, posing environmental and health hazards.
- Low flows in water bodies that receive discharges from wastewater treatment works reduces the dilution of effluent thereby impacting on the water quality of the resource.
- Intense precipitation can cause overflows from and damage to drainage infrastructure that has been designed to accommodate lower flows based on historical rainfall records.
- Intense precipitation creates high peak storm water flows that cause erosion and sedimentation when discharged to natural surface water bodies.
- Drought is likely to reduce the amount of flush water used in the drainage systems, potentially preventing the system from functioning properly, or even damaging it.
- Impermeable (built-up) areas increase the runoff water, overcrowding the sewage and drainage system and putting pressure on the availability of groundwater (links to water supply system).

Solid waste system

Includes: Systems of collection, transport, treatment, recycling and/or disposal of solid waste.

Reasons for vulnerability:

- Higher temperatures accelerate the decomposition of organic solid waste, attracting rodents and other organisms, and increasing the risk of health hazards to the population.
- Higher temperatures may cause waste in landfills or collection centres to ignite and cause fires, representing a hazard to environment and population.
- Climate change negatively impacting the livelihood of residents may result in increased waste scavenging/recycling and related health hazards.
- Floods and intense precipitation may result in the release of waste and pollutants from waste centres (e.g. landfills) into the environment.
- Failure in the energy supply system may cause the disruption of the waste-system and result in accumulated garbage in the city, constituting a health hazard and a nuisance to the population.

Buildings and built-up area

Includes: Commercial, industrial, residential buildings and stand-alone houses, both public- and privately-owned.

Reasons for vulnerability:

- Buildings located near a riverbank or on the coast are particularly vulnerable to floods and sea level rise, with potential for damage of the buildings' structures and the underground and lower stories. This also poses the risk of injury or death to humans.
- Built-up area located near a riverbank or in a coastal zone may be forced to relocate to a different geographical location due to floods or sea level rise, or a clear threat of them.
- Severe wind storms can threaten the stability of certain building structures, like roofs, windows. Trees located in the immediate proximity also pose a structural damaging risk during severe wind storms.

Urban green (areas) and biodiversity

Includes: Parks and their inventories, green-covered areas and unmanaged green areas in urban regions, which influence the diversity (number and variety of species) of plant and animal life within a region.

Reasons for vulnerability:

- Severe weather events can cause damage to urban green areas (fallen trees, damaged landscaping, etc). This in turn affects the quality of life—and likely the health—of the population.
- Increasing temperatures, the 'urban heat island effect' and/or droughts can have negative impacts on green areas (e.g. dead grass and trees) if they cannot adapt to climate change.
- Increased temperatures may give rise to alien and invasive species to proliferate and exert pressure on endemic species, potentially causing their extinction. Introduced invasive species (whether intentionally or not) that adapts better to the changing climate can jeopardize the survival of endemic species and unbalance the equilibrium of the ecosystem.
- Climate change negatively impacting the population of pollinating insects, birds and bats can have a negative direct effect on the fertilization process and biodiversity spread.
- Increased temperatures, heat waves and wind storms increase the risk of wild/bush fires, directly affecting flora and fauna.
- Maintenance of urban green in the sense of artificial watering exerts pressure on water availability and on the water supply system.

Health system

Includes: "A health system consists of all organizations, people and actions whose primary intent is to promote, restore or maintain health (…) A health system is therefore more than the pyramid of publicly owned facilities that deliver personal health services."[26]

Reasons for vulnerability:

- Increased temperatures, floods and droughts can harm human health and increase the proliferation of disease and pests, creating a higher demand for the system and possibly saturating it.
- Heat waves can cause dehydration and pose a health/death risk especially to the elderly.
- Floods can give rise to epidemic (e.g. through the proliferation of disease-transmitting mosquitoes or bacteria or viruses).
- Droughts or intense precipitation can lead to food shortage and cause malnutrition.
- Severe weather events may cause the demand for health services to soar and collapse the existing health facilities, causing the system to break if no appropriate emergency system is in place.
- The high frequency of international travel and immigration can help transport a disease between regions, putting pressure on the system in terms of increased demand and of unpreparedness to treat 'new' diseases.

Food production & supply system

Includes: All the production process, from agricultural planting, fishing and livestock rearing to processing to making the product available to the population.

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[26] WHO: Everybody's business. Strengthening health systems to improve health outcomes: WHO's framework for action, http://www.who.int/healthsystems/strategy/everybodys_business.pdf.

Reasons for vulnerability:

- Water scarcity and droughts can have a negative impact on crops, grassland and the amount of food grown, with a direct impact on the amount of food available for the population. This would create a need to procure food at distant locations or abroad.
- River floods and intense precipitation can have a negative impact on crops and cause reduced production of food. It would create a need to procure food at distant locations or abroad.
- Increased temperatures may have a similarly negative effect on crops.
- Severe storms may pose a threat to fishermen at sea—and the fishing production system.
- Increased water temperature in rivers, lakes and at sea can put pressure on species and cause their extinction. This also threatens the fishing production and consumption potential, as well as the livelihoods of fishermen and the related economy.
- Negative impacts on crop, grassland and food production from changing climate can have price effects on food and fuels (biofuels).

Governance and management system

Includes: For this purpose, the act of governing, managing and decision-making within a local or regional authority.

Reasons for vulnerability:

- Climate change, by preventing a stable availability of resources and through extreme weather events, exerts pressure on governance systems, demanding quick, yet well-planned, solutions to problems that are in cases new to the governing structures. This demands preparation (by new sets of tools in their operations including leadership knowledge transfer and capacity building), capacities, expertise and creativity that governing structures may be lacking with negative effects on the environment and pose health/death hazards to the population.
- Political decision-making that disregards climate change concerns can harm the accountability of local governments and, in turn, reduce the citizens' trust and belief in political institutions—whether or not the decision has evident negative impacts in the ecosystem or the population.
- Inappropriate/insufficient safety net instruments may worsen the negative impacts of severe weather events (e.g. communication for warning on severe weather events may rely on technologies that may give insufficient warning time). Possibility that the anticipated risk is not communicated to the population—on political decision grounds—to avoid chaos and economic costs (e.g. of arranging evacuation of population, etc.), especially if warning technologies are considered to be unreliable.

Social system

Includes: Communities, different social strata and their interactions, existing support systems to favour the inclusion of individuals into society.

Reasons for vulnerability:

- Severe weather events can cause instability, disruption of harmony, loss of livelihood and chaos among the population.

- Severe weather events demand a strong degree of community solidarity to protect those most vulnerable to the weather events. This required solidarity may be lacking, or supporting systems may not be in place to facilitate citizens' desire to be solidary (e.g. heat wave in France 2003).
- The negative effects of climate change can be worsen by reduced social cohesion and diffusion, whether it is due to changing lifestyles, more culturally-mixed cities and towns, etc.
- High density of population and immigration puts pressure on systems/resources/ecosystems (in the case of systems, particularly if they are not or cannot be expanded), stretching their operation/extraction/use to *peaks*. This may cause systems, e.g. water supply, to prove insufficient in delivering services to the population, especially in case of severe weather event.

General factors determining social vulnerability

Social vulnerability is partially the product of social inequalities—those social components that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond. This includes also individual characteristics of people (age, race, health, income, type of dwelling unit, employment). However, it also includes place inequalities—those characteristics of communities and the built environment, such as the level of urbanization, growth rates, and economic vitality, that contribute to the social vulnerability of places (Cutter et al. 2003).

There is a general consensus within the social science community about some of the major components that influence social vulnerability. These include: lack of access to resources (including information, knowledge, and technology); limited access to political power and representation; social capital, including social networks and connections; beliefs and customs; building stock and age; frail and physically limited individuals; and type and density of infrastructure and lifelines. Disagreements arise in the selection of specific variables to represent these broader concepts (Cutter et al. 2003).

Generic and not threat specific indicators for vulnerability

Name:	Vulnerability index for floods and heat for large urban zones (LUZ) in Europe
Source:	JRC (work in progress)[27]
Link:	
Maps:	Yes, cities in Europe
Purpose (thematic, policy):	To investigate the extent to which urban areas with different socio-economic characteristics and situated in different biogeographic regions of Europe will be affected by the consequences of climate change.
Audience, political level:	European level
Scale (spatial, temporal):	Spatial: aggregated for large urban zones (LUZ) , when data not available NUTS 3 level data was used Temporal: past socio-economic data, past climate (1961-1990) and climatic projections (2010-2100) based on the regional CLM model, forced by global climate model runs with ECHAM5/MPIOM
Components:	Exposure:

[27] Contact person: carlo.lavalle@jrc.ec.europa.eu

	1. tropical nights 2. river runoff under the A2 scenario
	Sensitivity: 3. Area and elevation of large urban zones in Europe 4. proportion of total population aged 75 and over 5. population density
	Adaptive Capacity: 6. gross domestic product 7. number of hospital beds per 1000 residents
Data availability (European, Cities)	Yes all data is available at EVDAB
Methods (scaling, standardization, combination):	2.+3. = fraction of each LUZ exposed to potential floods Quartile thresholds were used to assign a relative vulnerability score starting from very low and ending with high.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes The aggregation method is not described Yes Yes Yes, based on literature review and data availability
Limits:	Preliminary results

Name:	Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM)
Source:	Schröter et al. (2004a) PIK (Potsdam Institute for Climate Impact Research)
Link:	http://www.pik-potsdam.de/ateam/
Maps:	Yes (mapping tool available)
Purpose (thematic, policy):	To assess potential impacts of global change on ecosystem services in Europe, and to translate these impacts into maps of our vulnerability. Potential impacts and vulnerabilities of the sectors agriculture, forestry, carbon storage, water, nature conservation and mountain tourism in the 21st century were mapped.
Audience, political level:	Stakeholders include people and organisations in Europe who have an interest in information on ecosystem services and their vulnerability to global change. Relevant stakeholders for ATEAM include natural resource managers, planners and decision-makers, both within the private and the public sector.
Scale (spatial, temporal):	European data sets at regional scale 10’ x 10’ grid resolution over EU15 plus Norway and Switzerland, baseline 1990, future time slices 2020, 2050, 2080
Components:	Exposure: A consistent set of multiple, spatially explicit global change scenarios for A1f, A2, B1 and B2. 1. Past and future climate change scenarios for monthly values of five

	different climatic variables (monthly temperature, diurnal temperature range, precipitation, vapour pressure and cloud cover)
	Sensitivity: Range of state-of-the-art ecosystem models that represent the sensitivity of the human-environment system were used. Agriculture sensitivity indicators: 2. Agricultural land area (Farmer livelihood) 3. Soil organic carbon content 4. Nitrate leaching 5. Suitability of crops 6. Biomass energy yield Forestry sensitivity indicators: 7. Forest area 8. Tree productivity: growing stock, increment, age class distribution 9. Tree species suitability Carbon storage sensitivity indicators: 10. Net biome exchange 11. Carbon off-set by fossil fuel substitution Water sensitivity indicators: 12. Runoff quantity 13. Runoff seasonality 14. Water resources per capita 15. "Drought runoff" (the annual runoff that is exceeded in nine years out of ten) 16. "Flood runoff" (the mean maximum monthly runoff) Biodiversity and nature conservation sensitivity indicators: 17. Species richness and turnover (plants, mammals, birds, reptiles, amphibian) 18. Shifts in suitable habitats Mountains sensitivity indicators: 19. Elevation of reliable snow cover 20. Number of heat days
	Adaptive Capacity: Spatially explicit and quantitative generic index of adaptive capacity (macro-scale: province level). This index is based on six determinants which were identified by the IPCC Third Assessment Report: power, flexibility, freedom, motivation, knowledge and urgency. Used twelve indicators such as: 21. Gross domestic product 22. Female activity rate 23. Age structure 24. Literacy index 25. Urbanisation
Data availability (European, Cities)	1. – 25. from ATEAM/PIK
Methods	Fuzzy inference rules were applied to aggregate the individual indicator

(scaling, standardization, combination):	values into one generic measure of adaptive capacity per spatial unit. The resulting generic index captures one of many dimensions of adaptive capacity.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Good Yes Unknown Yes, used stakeholder dialogue to (1) identify indicators of changes in ecosystem services; (2) settle useful scales and units at which these indicators should be measured or modelled; (3) discuss thresholds for these indicators that represent limits outside which the adaptive capacity of the sectors is exceeded; and (4) present and discuss results as well as the format they are presented in (clarity of maps, graphs, etc).
Limits:	Empirical and theoretical evidence of how potential impacts and adaptive capacity can be combined into measures of vulnerability is very limited. Therefore, the project created a visual combination of these elements without quantifying a specific relationship. The resulting maps illustrate vulnerability in terms of negative potential impacts and limited adaptive capacity. All results are made available to stakeholders in form of a digital atlas (spatially and temporal explicit maps of Europe) of exposures, potential impacts, adaptive capacity and a dimension of vulnerability.

Name:	Key indicators for vulnerability
Source:	Brooks, N., Adger, W.N., Kelly, P.M. (2005): The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change, 15 (2), pp. 151-163. doi: 10.1016/j.gloenvcha.2004.12.006
Link:	
Maps:	no
Purpose (thematic, policy):	National level indicators of vulnerability and capacity to adapt to climate hazards to support policy
Audience, political level:	National governments and international organisations
Scale (spatial, temporal):	Spatial: national data Temporal: averaged, decadal data for past damages and system characteristics
Components:	Exposure: 1. Numbers of people killed by climate-related disasters per decade as percentage of national population
	Sensitivity:
	Adaptive capacity: 2. Population with access to sanitation

	3. Literacy rate (15-24 year olds) 4. Maternal mortality 5. Literacy rate over 15 years 6. Calorific intake 7. Voice and accountability 8. Civil liberties 9. Political rights 10. Government effectiveness 11. Literacy ratio (female to male) 12. Life expectancy at birth
Data availability (European, Cities)	1. Emergency events database (EM-DAT) 2. – 5., 11.-12. Human Development Index 6. UNEP/GRID- Geneva 7.-10 Kaufmann, Kray and Zoido-Lobaton governance data set
Methods (scaling, standardization, combination):	The 11 key adaptive capacity components were selected by correlation analysis with the exposure component. Standarisation based on ranges (quintiles) and scores between 1 and 5 Different weightings of the indicators based on expert interviews
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Yes Yes (except the weightings) Yes, except the KKZ data set on governance (heterogeneity of data) No
Limits:	The components are selected based on their correlation with mortality outcomes; they may be less appropriate for assessing economic vulnerability or non-fatal-outcomes. The statistical approach of selecting the indicators does not account for the hazard type, frequency and severity on mortality outcomes.

Name:	Social Vulnerability Index (SoVI) to environmental hazards for the United States
Source:	Cutter et al. (2003). Social vulnerability to environmental hazards. Social Science Quarterly 84(2), pp. 242-61.
Link:	
Maps:	US counties
Purpose (thematic, policy):	To define a robust set of variables that capture the characteristics of social vulnerability of counties, which then allows us to monitor changes in social vulnerability geographically and over time.
Audience, political level:	
Scale (spatial, temporal):	Spatial: all 3,141 U.S. counties Temporal: 1990 data
Components:	Exposure: /
	Sensitivity:

	1. Personal wealth (per capita income, percentage of households earning more than $75,000 per year, median house values, and median rents) 2. Age (median age) 3. Density of the built environment (No. commercial establishments/mi^2) 4. Single-sector economic dependence (employed in extractive industries) 5. Housing stock and tenancy (housing units that are mobile homes) 6. Race—African American (African American) 7. Ethnicity—Hispanic (Hispanic) 8. Ethnicity—Native American (Native American) 9. Race—Asian (Asian) 10. Occupation (employed in service occupations) 11. Infrastructure dependence (employed in transportation, communication, and public utilities)
	Adaptive Capacity: /
Data availability (European, Cities)	U.S. Census (City and County Data Books for 1994 and 1998)
Methods (scaling, standardization, combination):	After all the computations and normalization of data (to percentages, per capita, or density functions), 42 independent variables were used in the statistical analyses. Using a component analytic approach, these 42 variables were reduced to 11 independent components that accounted for about 76 percent of the variance. These components were placed in an additive model which equal weights to compute a summary score — the Social Vulnerability Index.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Yes Yes Unknown (Census data of the US) Based on literature review and statistical method
Limits:	Correlation between variables and damages caused by hazards is based on literature data, not on own statistical evaluation. It is not proven whether the appropriate variables were used in the beginning (e.g. why median age not percentage of elderly). The index explains the variability of the data which is only theoretically connected with the vulnerability to natural hazards; therefore the lack of correlation with presidential disaster declarations is not surprising.

Name:	The climate vulnerability index (CVI)
Source:	Sullivan, C. and Meigh, J. (2005). Targeting attention on local vulnerabilities using an integrated index approach: The example of the climate vulnerability index. Water Science and Technology 51(5), pp. 69-78.
Link:	
Maps:	

Purpose (thematic, policy):	Assessment of human vulnerability to develop adaptation strategies
Audience, political level:	International level
Scale (spatial, temporal):	variable
Components:	Exposure: 1. different scenarios
	Sensitivity: 2. Resource component, e.g. evaluation of water storage capacity 3. Access component 4. Environment component 5. Geospatial component
	Adaptive Capacity: 6. Capacity component 7. Use component
Data availability (European, Cities)	Dependent on the concrete choice of the components and the spatial scale.
Methods (scaling, standardization, combination):	Composite index as weighted average of all components. The weighs should be assigned by participatory consultation and expert opinion. Here they were all given the value one.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Yes, theoretically Yes, theoretically Unknown No
Limits:	A framework of deriving indices is described, a detailed selection and aggregation of the components is not part of the paper.

Further general vulnerability indicators, not evaluated in detail (from Kienberger 2010):

Source and name and of the composite indicator	**Scale/ Hazard**	**Sub indicators /Components**	**Method**
Cardona 2005a, 2005b: Four composite indicators to represent the	Global (country level)/ hazard'	1. The Disaster Deficit Index (DDI) measures country risk from a macro-economic and financial perspective according to possible catastrophic events.	- Designed to capture the inherent conditions between risk and development in terms of exposure and susceptibility in prone areas, as well as socio-economic fragility and

main elements of vulnerability		2. The Local Disaster Index (LDI) identifies the social and environmental risks resulting from more recurrent lower level events. 3. The Risk Management Index (RMI) brings together a group of indicators that measure a country's risk management performance. 4. The Prevalent Vulnerability Index (PVI) is made up of a series of indicators: **Exposure and susceptibility, ES:** • Population growth • Urban growth • Population density • Poverty-population below US$ 1 per day PPP • Capital stock • Imports and exports of goods and services • Gross domestic fixed investment • Arable land and permanent crops **Socio-economic fragility, SF:** • Human Poverty Index • Dependents as proportion of income measured using Gini index • Social disparity • Unemployment • Inflation, food prices • Dependency of GDP growth of agriculture • Debt servicing • Human-induced Soil Degradation **Lack of social resilience, LR:** • Human Development Index • Gerder-related Development Index • Social expenditure; on pensions, health, and education • Governance Index (Kaufmann) • Insurance of infrastructure and housing • Television sets per 1000 people • Hospital beds per 1000 people • Environmental Sustainability Index	lack of resilience regarding possible events - Each sub-index has been calculated through a set of indicators - Largely rooted in the political-ecological tradition of vulnerability science - Application of the analytical hierarchy process (AHP) integrating expert choice
Adger et al. 2004: Predictive Indicators of Vulnerability (PIV)	Global	1. population with access to sanitation 2. literacy rate, 15-24 year olds 3. maternal mortality 4. literacy rate, over 15 years 5. calorie intake 6. voice and accountability 7. civil liberties 8. political rights 9. government effectiveness	- Selection of social vulnerability indicators guided by historic hazard mortality - Attempt to link social vulnerability with climate adaptation (climate variability and climate change) - Set of eleven indicators based on correlations with decadal hazard mortality; unweighted combination

		10. literacy ratio (female to male) 11. life expectancy at birth	within an index (no ranking, classification of different vulnerabilities)
Vincent 2004: Social Vulnerability Index to climate change in Africa (SVA)	Africa (country level)/ water avail-ability	1. Economic well-being and stability: • Standard of living/poverty • Change in % urban population 2. Demographic structure • Dependent population • Proportion of the working population with HIV/AIDS 3. Institutional stability and strength of public infrastructure • Health expenditure as a proportion of GDP • Telephones • Corruption 4. Global interconnectivity • Trade balance 5. Natural resource dependence • Rural population	- Expert weighted index of five indicators; however the indicators are not directly related to 'water availability' - Draws from the global climate change research community who align social vulnerability with adaptation capacity
Briguglio 2003 and Briguglio 2004: The Composite Vulnerability Index for Small Island States	Country level focusing on develop-ing small island states/ hazard'		- Point out the intrinsic vulnerability of small island states in comparison to large countries which possess several advantages associated with their large scale - Application of weighted least square (determination of weights through regression) routines to integrate the basic (4) indicators
Kumpulainen 2006: Vulnerability concepts in hazard and risk assessment	Regional	1. Damage potential: GDP/capita; population density; tourism; culturally significant sites; significant natural areas; fragmented natural areas 2. Coping capacity: education rate; dependency ratio; risk perception; level of mitigation; medical infrastructure	The indicators were weighted in a way that the overall regional vulnerability is 100%. Integrated vulnerability index: regional GDP/capita 30%, population density 30%, fragmented natural areas 10% (only 10% because this component only depicts one aspect of ecological vulnerability), national GDP/capita 30%.
O´Brien et al. 2004: Mapping vulnerability to multiple stressors: climate change and globalization in India	India	Adaptive capacity: biophysical (soil conditions (quality and depth), ground water availability); socio-economic (levels of human and social capital, presence or lack of alternative economic activities); technological (availability of irrigation and quality of infrastructure).	To measure adaptive capacity, significant biophysical, socio-economic, and technological components that influence agricultural production were identified. To measure sensitivity under exposure to climate change in regard to dryness and monsoon dependence, they constructed a climate sensitivity index (CSI).

Further reading about integrated assessments:

Greiving, S., Fleischhauer, M., Lückenkötter, J. (2006). A methodology for an integrated risk assessment of spatially relevant hazards. Journal of Environmental Planning and Management 49, pp. 1-19.

7.1.2 Heat-related discomfort and mortality/morbidity

Effects

Heat waves mainly affect human health. Studies of heat waves and mortality in the United States (see overview in Reid et al. 2009) demonstrate that days with increased temperature or periods of extended high temperatures have increased heat-related mortality, cardiovascular-cause mortality, respiratory mortality, heart attacks, and all-cause mortality. During heat waves, calls to emergency medical services and hospital admissions also increase.

Components determining exposure

Mortality and morbidity are influenced by thermal stress, which is caused by air temperature, thermal radiation, humidity and wind velocity. This can be combined into a complex heat stress index (e.g. the “Klima-Michel” of the German Meteorological Institute DWD). Especially during night times the urban heat island effect is pronounced with temperature differences between urban areas and surroundings but also between different city districts up to 10°K. An important component for heat stress is the long-wave thermal radiation during night times (Wilhelmi et al. 2004). For large-areas, high surface temperatures can be used as indicators for heat stress and increased mortalities due to heat waves (Huynen et al. 2001, Kysely 2004). The maximal daily temperature is highly correlated with the mortality rate in Vienna, however the air quality (NO_2, O_3) did not increase the temperature influence (Moshammer et al. 2009).

Components determining sensitivity

Urban heat islands are due to high building density and widely impervious surfaces. The build environment in cities has a large surface with a high thermal capacity. Also in the cities the energy consumption due to transport and technical processes is high. Therefore, the temperature and thermal radiation of a city is influenced by its land use and surface structure (e.g. the relation between buildings density and the height of the buildings, the distribution of blue and green areas), its building fabric and design as well as its population density and city size (Oke 1973, Moeller 2004, Katzschner 2010)that varies inside a city (Katzschner 2010).

Thermal stress depends on acclimatisation of the population. Thus, at high temperatures more people die in London as in Madrid (Koppe 2005). Individual susceptibility depends on poor acclimatisation, dehydrogenation, poor fitness, excess of weight and especially the age (Koppe et al. 2004): children below 5 years and especially adults above 65 years are most vulnerable. In Vienna, also women have higher risk of heat related mortality than men (Moshammer et al. 2009). Some components are over-proportional important when combined, e.g. socially isolated seniors are rated as highest-risk group in Toronto (Rinner et al. 2010). UK’s National Heatwave Plan (2009) identifies components that increase an individuals risk during a heat wave, including:

1. Older age: especially women over 75 years old, or those living on their own who are socially isolated, or in a care home.

2. Chronic and severe illness: including heart conditions, diabetes, respiratory or renal insufficiency, Parkinson's disease or severe mental illness. Medications that potentially affect renal function, the body's ability to sweat, thermoregulation or electrolyte balance can make this group more vulnerable to the effects of heat.
3. Inability to adapt behaviour to keep cool: having Alzheimer's, a disability, being bed bound, too much alcohol, babies and the very young.
4. Environmental components and overexposure: living in urban areas and south facing top floor flats, being homeless, activities or jobs that are in hot places or outdoors and include high levels of physical exertion.

Components determining adaptive capacity

Individual heat related mortality is influenced by income level (Klinenberg 2002), because good isolated and tempered flats are more costly than flats with a low building standard. Thus, citizens in city areas with low social status (approximated with low real estate prices) have higher mortality rates and lower live expectancy than in areas with higher social status (Moshammer et al. 2009). Also components such as level of social isolation (McGeehin and Mirabelli 2001) and education level (Ballester et al. 1997) may be important. In Reid et al. (2009) socio-economic components influencing vulnerability were discussed in detail. To understand the adaptive capacity of the socio-economic system the following variables could be used (Harvey et al. 2009):

- GDP
- Education level
- Number of hospital beds/population
- Number of doctors/population
- Countries / regions with a heat wave action plan in place
- Number of homes with air conditioning and/or ventilation
- Proximity to green space

Adaptation options in regard to the urban design and structure have the potential to help cool and reduce discomfort in urban environments in hot, dry weather by improving the micro-climate, e.g. increasing the shading of pavements by planting of trees, creation of blue and green spaces, green faces of buildings, using of reflecting face materials in areas not used by peoples (Georgi and Dimitriou 2010, Katzschner 2010)

Other drivers than climate change influencing the issue

Because the old people, living alone are especial vulnerable to heat waves, demographic change will influence future vulnerability to heat waves.

Heat wave related indicators

Name:	**Components influencing the vulnerability of European populations to heat waves**[28]
Source:	**Harvey et al. 2009**
Link:	Not published yet, contact DG ENV (project reference ENV.G.1/ETU/2008/0092r)
Maps:	No
Purpose (thematic, policy):	Identification of those considered to be at risk from heat waves.
Audience, political level:	European level: European public health systems and service provision
Scale (spatial, temporal):	Spatial: European, Temporal: mainly observed data, except tropical nights (2071-2100 (A2))
Components:	Exposure: 1. Warm Spell Duration Index over the period 1976-2006 2. Tropical nights (night time temperature)
	Sensitivity: 3. Population demographics – age classes 4. Elderly population – over 60 years
	Adaptive Capacity: 5. Gross domestic product in Euros/inhabitant 6. Education level: ISCED6 Second stage of tertiary education leading to an advanced research qualification - level 6 (ISCED 1997)
Data availability (European, Cities)	1. KNMI, NL (EU 27, 50km^2, 1971-2006, no future projections) 2. JRC (unknown coverage and resolution 1961-1990, 2071-2100 (A2)) 3. Eurographics (EU27, NUTS 2 and 3 no future projections) 4. Eurostat (unknown) 5. Eurostat(EU 27, NUTS2, 2002-2006, no future projections) 6. Eurostat (EU 27, NUTS2 and 1, 2004-2006, no future projections)
Methods (scaling, standardization, combination):	No suggestions, only data availability to form an indicator were analysed.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes No, no aggregation method is given No, no aggregation method is given Good Yes (components selected based on literature)

[28] This is not a real indicator – in other words only developed to demonstrate a process rather than to be used for policy. However, the data sources are probably relevant.

Limits:	No aggregation methodology, only data availability to form an indicator was analysed. There is no easy way to decompose the population density into component demographic groups or to downscale the NUTS 3 demographic data to 1 km grid cells.

Name:	**Regional vulnerability indicator for heat waves**
Source :	**Kropp et al. 2009**
Link:	
Maps:	yes
Purpose (thematic, policy):	Describing the susceptibility of the population of NRW to heat waves to support the adaptation strategy of North-Rhine Westphalia, Germany
Audience, political level:	State government of North-Rhine Westphalia, Germany
Scale (spatial, temporal):	Spatial: for North-Rhine Westphalia, Germany (counties, partly municipalities) Temporal: A1B SRES scenarios for 2036-2065 (2050) with RCMs STAR and CCLM compared to 1961-1990, development of population for 2025 compared to 2007
Components:	Exposure: 1. Past or expected heat wave days
	Sensitivity: 2. Fraction of impervious areas 3. Population density 4. Fraction of people above 65 years (past and projected)
	Adaptive Capacity /
Data availability (European, Cities)	1. Regional climate models for Germany 2. NRW database 3. NRW database 4. NRW database
Methods (scaling, standardization, combination):	Fuzzy Logic to quantify uncertainty and use of regional thresholds for scaling and standardizing indicators as well as for aggregating them 2.+3. = potential for heat island 2.+3.+4. = sensitivity of the region +1. (exposure) = vulnerability Increase of heat wave days or fraction of people above 65 years leads to an increase of susceptibility
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes No, description of aggregation method is too thin Yes, easy to comprehend Data availability unknown for Europe Yes, but very simple
Limits:	No components for adaptive capacity (e.g. existence of heat warning systems)

	included, thus no social learning aspect for future events included. Really only a potential impact indicator (exposure + sensitivity).

Name:	**Cumulative heat vulnerability index for the USA**
Source:	**Reid et al. 2009**
Link:	
Maps:	National map of cumulative heat vulnerability index by census tract for counties
Purpose (thematic, policy):	Creation of a cumulative heat vulnerability index and maps for US-wide comparison to give guidance at regional and national scales for further analysis and intervention
Audience, political level:	Regional to national decision makers
Scale (spatial, temporal):	Spatial: US census tract (counties) Temporal: past
Components:	Exposure:
	Sensitivity: 1. Percent population of a race other than white 2. Percent population ≥ 65 years of age 3. Percent population ≥ 65 of age living alone 4. Percent population ever diagnosed with diabetes 5. Percent census tract area not covered in vegetation
	Adaptive Capacity: 6. Percent population below the poverty line 7. Percent population with less than a high school diploma 8. Percent population living alone 9. Percent households without central air conditioning 10. Percent households without any air conditioning
Data availability (European, Cities)	Census data for US, unknown for Europe
Methods (scaling, standardization, combination):	A component analysis was used to deal with potential multi collinearities. All 10 variables were calculated so that an increase in value denotes an increase in vulnerability. Census-tract–level data for most variables were obtained. Spearman's correlation coefficients were calculated and principal components analysis was used to obtain 4 independent components, which were normalized and divided into 6 categories with rising values. The component scores were not weighted but added cumulatively. There is the danger that lack of air conditioning is driving the vulnerability index.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability:	 No Yes No Unknown (census data)

Knowledge based:	Yes (components selected based on literature review)
Limits:	No exposure data. Correlation between components and whole index with heat related mortality is missing. Integration of exposure is missing, components for adaptive capacities not projected into the future: thus no future vulnerability can be calculated. Really only a sensitivity indicator.

Name:	**Heat related risks**
Source:	**Lindley et al. 2006**
Link:	
Maps:	Yes: Greater Manchester and Lewes
Purpose (thematic, policy):	Application of a generic framework for climate related risk management and a coupled methodology for screening relative degrees of associated risk within the urban environment
Audience, political level:	Science, city planners
Scale (spatial, temporal):	Spatial: 5 km grid Temporal: the 2020s, 2050s and 2080s for temperature and population changes
Components:	Exposure: 1. 90th percentiles of current and future daily maximum and minimum temperatures for July and August (hazard layer, classified in 4 classes= index)
	Sensitivity: 2. Urban Morphology Types (UMT) based on classified land use data (urban system layer) checked with local knowledge 3. Relative density of population age > 75 or nearest banding 4. Relative density of population age < 4 or nearest banding 5. Relative density of population health 6. Relative density of dependency (residential)
	Adaptive Capacity: /
Data availability (European, Cities)	1. BETWIXT project 2004 for UK 2. UK National Land Use Database (NLUD) 3.-6. CURE, Census 2001 for UK
Methods (scaling, standardization, combination):	1. + 2. = spatial likelihood of high temperatures for each urban morphology unit (exposure layer) 3. +4. +5. +6. = elements at risk layers combined to vulnerability index layer, which is classified into 4 classes (vulnerability index) 1. + (3. +4. +5. +6.)= Hazard index combined with vulnerability index to risk layer
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes No, combination of different layers by using classes (indices) unclear, No, effect of UMTs unclear Do not know, effects of population changes not investigated in detail Yes, components selected based on literature review

Limits:	Simple structure, but complicated details when aggregating the different components. Adaptation capacity components are missing.

Name:	**Neighborhood-level heat vulnerability assessment**
Source:	**Rinner et al. 2010**
Link:	
Maps:	Yes for the city of Toronto
Purpose (thematic, policy):	Spatial patterns of heat vulnerability were visualized using maps representing individual exposure and sensitivity indicators, composite vulnerability indices, and geographical hot spots of vulnerability to assess cartographic design decisions in creating heat vulnerability maps.
Audience, political level:	This study is part of an ongoing project which aims to identify vulnerable populations and places within the City of Toronto, Canada, in order to support targeted response and mitigation.
Scale (spatial, temporal):	Spatial: neighbourhoods of Toronto (census trace levels =population of 2500-8000), Temporal: past data (2001 and 2006 census data, 2003 satellite image)
Components:	Exposure: 1. Outdoor surface temperature of 3rd September 2003
	Sensitivity: 2. Dwellings requiring major repairs 3. Dwellings constructed before 1986 4. Apartments in buildings with five or more storeys 5. Dwellings rented 6. Low income persons before tax 7. Speaking neither English nor French 8. Recent immigrants 9. Visible minority 10. People without a degree 11. Persons aged above 75 yrs 12. Working age with disability 13. Rates of ambulatory hospital visits for circulatory and respiratory diseases 14. Persons aged over 65 yrs 15. Persons aged over 75 yrs in private households 16. Low income seniors 17. Seniors without a degree 18. Seniors without command of a official language 19. Seniors who are recent immigrants 20. Visible minority seniors
	Adaptive Capacity: Included in sensitivity components (education level, income level, dwellings constitution)
Data availability (European,	1. Satellite thermal image 2. – 19. 2001 and 2006 Canadian Census, 2006 census target profile of seniors

Cities)	
Methods (scaling, standardization, combination):	Maps for each component were created. Multiple components were weighted and combined in composite index maps. The composite indices were calculated using the ordered weighted averaging (OWA) multi-criteria analysis method (Yager 1988). The OWA method supports an explicit definition of decision strategies (pessimistic to optimistic strategies). Hot spots were determined using local indicators of spatial association (LISA) in cluster maps for the single indices. 1. General population index: 2. (5 %) + 3. (5 %) +4. (5%) + 5. (5%) + 6. (5 %) + 7. (10%) + 8. (5 %) + 9. (5 %) + 10. (5 %) + 11. (15 %) + 12. (10 %) + 13. (15 %) 2. Index targeting seniors: 14. (10 %) + 15. (25 %) + 16. (25 %) + 17. (10 %) + 18. 10 %) + 19. (10 %) + 20. (10 %)
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Difficult because of the complex methods used to weight and aggregate the data No, the OWA and LISA methods are rather complicated Unknown (census data) Partly: components selected based on literature review and local knowledge, weighting and aggregating unclear.
Limits:	Only past data have been used, the selection of components is only an example (based on local conditions), the method of aggregation and weighing is interesting but complicated.

Name:	**Vulnerability Indicators for Extreme Heat and Human Health**
Source:	**Preston et al. 2008**
Link:	http://www.csiro.au/resources/SydneyClimateChangeCoastalVulnerability.html
Maps:	Yes: vulnerability to heat in the Sydney Coastal Councils Groups region
Purpose (thematic, policy):	Part of a wider study with the aim to assess the potential biophysical effects of climate change including examining local adaptive capacities. The vulnerability maps shall be used to initiate a dialogue among researchers and stakeholders and a bottom-up assessment of local governments.
Audience, political level:	Researchers, stakeholders, local government
Scale (spatial, temporal):	Spatial. A spatially homogenous data scale of a 90 metre grid was used Temporal: current data used, except 2030 for climate data, 2019 for population projections
Components:	Exposure (Climate): 1. Average Temperature (present January maximum and minimum) 2. Temperature Variability (present days > 30 °C) 3. Projected Temperature (change in average DJF maximum temperature in 2030)
	Biophysical Sensitivity: 4. Land Cover (Land use, Population and Road Density) Socio-economic Sensitivity: 5. Housing Conditions (housing as multi-unit dwellings) 6. Population (population >64yrs, > 64 and living alone, <5, projected population

	growth to 2019)
	Economic Adaptive Capacity: 7. Access to technology (households with internet access) 8. Financing (Median home loan repayment, home ownership, household income, households requiring financial assistance) 9. Education (>12 yrs) 10. Human Resources (non-English speaker) Social Adaptive Capacity: 11. Responsibility (council current ratios, per capita business rates, per capita residential rates, per capita community service expenses, per capita environment and health expenses) 12. Leadership (?) 13. Community (?) 14. Priority (?) 15. Equity (?)
Data availability (European, Cities)	
Methods (scaling, standardization, combination):	Differentiation between bio-physical and social/ecological vulnerability. A simple conceptual model was used to structure components based on the three elements of vulnerability which were further differentiated into biophysical and socio-economical sensitivity, economic and social adaptive capacity. For each element (exposure (1-4), sensitivity (5+6) and adaptive capacity (7-15)) a data layer was created by a sum of the components, sums were rescored to a scaled from 1 to 9 based upon quintiles. The three data layers were integrated by summation the scores after weighting them due to expert judgement (0,5;1;2, adaptive capacity was given the weight 0,5), the result again being rescored.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Partly (method to aggregate components not completely explained, expert judgement on weights of vulnerability elements difficult) No, because many data needs for adaptive capacity which is only marginally weighted Unknown (census data) Yes
Limits:	Adaptive Capacity components based mainly on economic data, although wider conceptual approach was wanted. The aggregation of the components for one element layer is unclear (summation without normalisation?).

7.1.3 Decreased precipitation, water scarcity and drought

Effects

Water stress will occur when there is an imbalance between water supply (or availability) and demand. Water stress can affect many different sectors, regions and receptors, e.g. agriculture, tourism, energy supply. Water scarcity does not need to have a climatic origin (Kallis 2008). It refers to average long-term water imbalances, combining low water availability with a level of water demand exceeding the natural recharge. In contrast, a drought occurs when a temporal lack of water availability is caused by abnormal climate and is causing damage to humans or the environment. Global warming is likely to exacerbate droughts in many semiarid, snow-fed and coastal basins (EC 2007, Kallis 2008). Drought will affect water resources quantitatively and qualitatively, e.g. by increased eutrophication and danger of toxic algae blooms in water bodies. Reduced drinking water supply increases the need for more advanced treatment or desalination (EEA 2010b).

Components determining exposure

For assessing water scarcity and droughts data on long-term and short-term water availability is needed, e.g. average precipitation, rainfall effectiveness, rain timing, spatial distribution of rainfall, occurrences of droughts and hydro-environmental components such as river discharge, groundwater level, soil moisture (Kallis 2008). Projections of changes in water availability are available for Europe (EEA 2008, EC 2009a). Observed and projected data is available for river flow (JRC). Observed data is also available across Europe from the European Drought Observatory.

Components determining sensitivity

Sensitivity to water scarcity and droughts depends on the relation between water supply and water demand. To assess the availability of water across Europe the EEA use a 'Water Exploitation Index (WEI). This index expresses annual total water abstraction per year as a percentage of available long-term freshwater resources (based on figures from the 1990s). Figures suggest that over the last 10 to 15 years the WEI has decreased due to economic and institutional changes although nearly half of Europe's population still lives in water-stressed countries (approx. 266 million inhabitants[29]). Sectoral reporting of water use exists via Eurostat, which is available through the EEA as part of the WEI. However, consistent, robust data on projected changes in demand from different sectors is not currently available. This includes sectoral use of portable versus non-portable water, projected changing demand from sectors, requirements for water treatment including desalinisation; and finally land use and land cover change (Harvey et al. 2009).

Components determining adaptive capacity

The possibilities to manage the water demand or supply to reduce shortages in water availability influences future vulnerability of cities. For example, a drought management plan should aid the decision-making process during a drought to distribute and use water most effectively and help minimise wastage. Consumers must be motivated and educated to use water efficiently and share the limited amounts available, e.g. by water pricing (EEA 2010b). Investments in water conservation and water saving technologies are necessary in high drought risk areas. Water scarcity can be reduced by the use of alternative sources to supply water such as desalination, rainwater harvesting and reclaimed (or recycled) water. Treated wastewater can be used to top up depleted aquifers (EEA 2010b).

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[29] http://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources/use-of-freshwater-resources-assessment-1.

Other drivers than climate change influencing the issue

Urban sprawl and soil sealing can decrease rainwater infiltration in the soil and thus decreasing groundwater recharge because discharges from urban wastewater treatment plants are generally returned to rivers rather than augmenting groundwater stocks. Water demand is affected by population growth and urbanisation, influenced by household size, income, consumer behaviour and tourist activities. Technological developments, including the degree to which leakage in the public water supply system is addressed, also play an important role (EEA 2009c).

Water scarcity and drought related indicators

Name:	**Indicators for U.S. water resources**
Source:	**Lane et al. 1999**
Link:	
Maps:	Yes (US socio-economic indicators under current climate)
Purpose (thematic, policy):	Investigation of the integrated impacts of potential global warming on water resources
Audience, political level:	unclear
Scale (spatial, temporal):	Spatial: 18 U.S. water resources council regions, averaged data Temporal: present (1990) and future (2100) data, future data from GCM data, projections for water demand, power, population, GDP
Components:	Exposure: 1. Climate and economic scenarios 2. Runoff ratio
	Sensitivity: 3. Storage vulnerability (function of reservoir storage capacity and annual yield) 4. Hydropower 5. Water quality 6. Coefficient of variation
	Adaptive Capacity: 7. Consumptive use 8. Relative poverty 9. Import demand ratio 10. Withdrawal ratio 11. Dependence ratio
Data availability (European, Cities)	Numerous sources, literature data and own investigations (on different spatial scale, e.g. for each reservoir, averages over a region
Methods (scaling, standardization, combination):	16 initial components were selected based on literature review, the ones not independent, practical (not estimated for the future) and measurable were excluded to retrieve 10 components. These were calculated for past and future conditions and compared to warning thresholds from literature or from own

	judgment. The components were only aggregated graphically as percentage of threshold (e.g. in stars).
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No difficult yes for selection, no for assessment by thresholds, only graphic aggregation Unknown, literature and scenario data uncertain Yes (literature review)
Limits:	Thresholds are helpful, but often they do not exist. The components are only graphically aggregated. The components for adaptive capacity could also be counted as sensitivity, e.g. GDP and poverty are both sides from one medal. Positive components for adaptive capacity (e.g. measures to reduce demand) are not integrated.

Name:	**Indicators of vulnerability to climate change**
Source:	**Füssel 2010b**
Link:	
Maps:	no
Purpose (thematic, policy):	To inform the pertinent political debate on international adaptation funding within the framework of the UNFCCC by providing robust information on the degree of inequity between responsibility/capability and vulnerability for different climate-sensitive sectors and for different conceptualizations of vulnerability to climate change.
Audience, political level:	International adaptation funds within the UNFCCC framework
Scale (spatial, temporal):	Spatial: national data Temporal:
Components:	Exposure: 1. Median of the projected change in precipitation 2. Standard deviation of the projected change in precipitation between 1961-1990 and 2040- 2069, based on an ensemble of 19 general circulation models (GCMs) that have contributed to the IPCC Fourth Assessment Report (Parry et al. 2007) (see Appendix B), and 3. Median of the projected change in runoff simulated by the global hydrological model LPJmL 3.3 for the same period and GCM ensemble
	Sensitivity: 4. Current population-weighted precipitation, 5. Renewable water resources per person, and 6. Water use ratio.
	Adaptive Capacity: 7. Percentage of households with improved water supply and 8. Percentage of households with improved sanitation (WHO/UNICEF, 2006).
Data availability (European, Cities)	Literature review and international database

Methods (scaling, standardization, combination):	No aggregation
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	
Limits:	

7.1.4 Wildfires

Effects

Disturbance to forest and bush ecosystems have consequences for various sectors and activities including biodiversity, economic impacts and mitigation targets (Harvey et al. 2009). Especially in southern Europe, wildfires can directly threaten urban environments.

Components determining exposure

Wildfires are often closely related to the weather of the present and previous days, while the weather of forthcoming days may dictate the duration of the fire. Hotter temperatures often lead to lower moisture content in the air and soil, which leads to a higher combustibility of fuels. The probability of the occurrence of wildfires is estimated fairly well by knowing the weather conditions (Ho and Odening 2009). The actual fire risk can be monitored, for example by the Fire Weather Index (FWI) that uses daily weather observations to estimate the moisture content of different potential fuel classes. Other components influencing exposure are wind direction and speed. Climate change increases a number of risks to forests as they may potentially be harmed by changes in temperature and precipitation both from gradual annual or seasonal changes and in the form of extreme events, such as drought, heat waves and storms (Harvey et al. 2009).

Components determining sensitivity

Next to weather conditions, wildfire intensity and severity are based on fuel load and topography. Trees, branches, needles, or any other combustible materials such as homes and other structures, are considered fuel. Topography in combination with wind speed and direction play a role in the spread of fire, since wind provides oxygen and assists the fire in extending to neighbouring unburned areas. The size of the fire may be greatly influenced by characteristics of the land, such as the fuel type, the connectivity of fuels, the slope and aspect of the location, proximity to road and other human activities, whether the land is urban, and so on. In practice, the urban landscape can be considered as a fuel type, since the fuel type of wooden homes and asphalt-paved roads conduct fire differently from forested land or chaparral (Ho and Odening 2009). Ho and Odening (2009) found that mountain areas have higher probabilities of ignition than coastal regions in Southern California. The capacity of trees and the ecosystem to respond to changes or to be resilient to potential changes influence the fire risk (Harvey et al. 2009):

- Density and distribution of species,
- Proximity to urban areas,
- Forest stand height,
- Inter-relationship between fire and other types of disturbance (e.g. pests, disease, wind damage).

Components determining adaptive capacity

Investigating the fire causes in Italy showed that the main cause of fires is arson and other causes include negligence of one form or another (EC 2003). Thus, raising awareness of climate change is required as it is the behaviour of forest managers that is the weakest link in the general aim of reducing forest fire risk. The management in place – such as presence of fire watch towers and the nature of road network or the ability to implement particular adaptation measures, such as financial capital to invest in forest protection measures and regulatory capacity to protect forests and enforce relevant legislation - is determining the adaptive capacity of forests (Harvey et al. 2009). As result of the bushfires in Victoria, Australia, different proposals were made to protect settlements: building regulations need to contain specific standards for the construction of buildings in wildfire-prone areas, especially for the construction of non-residential buildings used by vulnerable groups—for example, schools, hospitals, child care centres and aged care facilities. In order to improve information and understanding of wildfires, good mapping of wildfire risk areas are needed. In areas where the wildfire risk is high, development should be restricted. Also, the government should develop and implement a voluntary retreat and resettlement strategy—including non-compulsory land acquisition—for existing developments in areas at unacceptably high wildfire risk (Victorian Bushfires Royal Commission 2010).

Other drivers than climate change influencing the issue

Urban sprawl into high wildfire risk areas is influencing the potential damages by wildfires.

Wildfire related indicators

There are a number of tools to help fire managers determine the severity of fire and make decisions with regard to resource allocation and strategic fire management. So called fire indices have been defined for that purpose: Some indices are simply based on weather information, while others involve additional information on the forest such as vegetative cover and topography. These indices are often based on modelling of the physical components of fire. One example is the U.S. National Fire danger Rating System (NFDRS), which uses current and historic weather and fuel information to create indices, which are then expressed in maps. The Canadian Wildland Fire Information System generates maps describing the fuel conditions and the likelihood of ignition. Relating specifically to weather conditions, the Fosberg fire weather index, which uses temperature, relative humidity and wind speed to evaluate the potential influence of weather on a wildland fire. The Keetch- Byram drought index utilizes precipitation to estimate the dryness of the soil and duff layers. To date, the accuracy of these tools has not been thoroughly tested, leaving no consensus on the overall superiority of any one tool over the others (Ho and Odening 2009).

In Europe, the European Commission set up in 1997 a research group to work specifically on the development and implementation of advanced methods for the evaluation of forest fire risk and for the estimation of burnt areas in the European Union. This group is currently working as part of the Institute for Environment and Sustainability of the European Commission Joint Research Centre (JRC).

Their collaboration with the relevant services in the Member States, under the coordination of DG Environment, led to the development of the European Forest Fire Information System (EFFIS). The purpose of EFFIS is to provide information for the protection of forests against fire in Europe addressing both pre-fire and post-fire conditions. It also centralizes the national fire data that the Member States collect through the national forest fire programs.

The EFFIS is structured in several modules, some of them already operational and others under development. For theEVDAB database the results of the EFFIS Rapid damage Assessment module, module that replaced the old EFFIS Damage Assessment from 2004 onwards, has been considered. The Rapid damage Assessment module provides reliable and harmonized estimates of the areas affected by forest fires during the fire season. The evaluation focuses mainly on Southern Europe and is based on the analysis of satellite imagery and geographic information. Since 2000, cartography of all the burned areas larger than 50 ha is produced every year through the processing of MODIS satellite imagery.

For the selected European larger urban areas two indicators were derived and mapped from the available historic fire series (i) total burned area in hectares and (ii) total number of observed large fires.

Wild fire related vulnerability indicators

Name:	**Vulnerability Indicators for Bush fires**
Source:	**Preston et al. 2008**
Link:	http://www.csiro.au/resources/SydneyClimateChangeCoastalVulnerability.html
Maps:	Yes: vulnerability to bush fires in the Sydney Coastal Councils Groups region
Purpose (thematic, policy):	Part of a wider study with the aim to assess the potential biophysical effects of climate change including examining local adaptive capacities. The vulnerability maps shall be used to initiate a dialogue among researchers and stakeholders and a bottom-up assessment of local governments.
Audience, political level:	Researchers, stakeholders, local government
Scale (spatial, temporal):	Spatial. A spatially homogenous data scale of a 90 metre grid was used Temporal: current data used, except 2030 for climate projections
Components:	Exposure (Climate): 1. Average temperature (present January average maximum) 2. Temperature variability (present days > 30 °C) 3. Projected temperature (change in average DJF maximum temperature in 2030) 4. Average rainfall (present annual average) 5. Rainfall variability (present average annual 10% percentile) 6. Projected rainfall (projected average annual rainfall change in 2030)
	Biophysical Sensitivity: 7. Land Cover (Land use, Vegetation cover, annual primary production) 8. Topography (slope, aspect) Socio-economic Sensitivity: 9. Population (population and road density)
	Economic Adaptive Capacity: 10. Access to technology (households with internet access) 11. Financing (Median home loan repayment, home ownership, household

	income, households requiring financial assistance) 12. Education (>12 yrs) 13. Human Resources (non-English speaker) Social Adaptive Capacity: 14. Responsibility (council current ratios, per capita business rates, per capita residential rates, per capita community service expenses, per capita environment and health expenses)
Data availability (European, Cities)	
Methods (scaling, standardization, combination):	Differentiation between bio-physical and social/ecological vulnerability. A simple conceptual model was used to structure components based on the three elements of vulnerability which were further differentiated into biophysical and socio-economical sensitivity, economic and social adaptive capacity. For each element (exposure, sensitivity and adaptive capacity) a data layer was created by a sum of the components, sums were rescored to a scaled from 1 to 9 based upon quintiles. The three data layers were integrated by summation the scores after weighting them due to expert judgement (0,5 ; 1; 2, adaptive capacity was given the weight 0,5), the result again being rescored.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Partly (method to aggregate components not completely explained, expert judgement on weights of vulnerability elements difficult) No, because many data needs for adaptive capacity which is only marginally weighted Unknown (census data) Yes
Limits:	Only present storm surge data was used. Adaptive capacity components based mainly on economic data, although wider conceptual approach was wanted. The aggregation of the components for one element layer is unclear.

7.1.5 Fluvial floods, flood claims and health effects of flooding

Effects

Fluvial floods can be defined hydrologically in terms of extreme water levels or discharge of rivers. They can have adverse impacts on the social system, the natural system or the built environment. In urban areas river flooding results in considerable economic losses due to damage to infrastructure, property and agricultural land, and indirect losses in or beyond the flooded areas e.g. interrupted power generation. They are also in numerous cases associated both directly and indirectly with the loss of human life, population displacement and adverse affects on human and animal health (EEA 2008). Vulnerability of human health from flooding includes exposure to vector-borne (e.g. rodents, mosquitoes) and water borne diseases from standing water and sewage, waste water, agricultural run-off, impacts on drinking water, drowning, heart attack, injuries, poisoning, post-traumatic stress disorder (Hajat et al. 2005). Components that place individuals at risk are likely to be similar to those at risk from heat waves (e.g. determined by age, existing health etc.). Observations of river discharge data show increased winter flows and river flooding in north-west Europe and eastern Europe (IPCC 2007). While seasonal river discharge rates have increased in some regions, no significant general climate-related trends have been observed in the frequency of extreme river flood levels (EEA 2008). Annual runoff is projected to increase in northern Europe by 9 to 22% by the 2070s (for the A2 and B2 SRES scenarios), and decrease by 6 to 36% for southern Europe (Alcamo et al. 2007). Flood frequency, particularly flash and urban floods, is expected to increase (EEA 2008) in north-west and eastern Europe. According to the available sources, increased river flooding of urban areas is expected to get worse across Europe (IPCC 2007).

Components determining exposure

Data on river flows and past river floods, including severity, duration, return periods and timing of flooding events, can be used to describe exposure of regions to floods (Harvey et al. 2009). On a European scale several assessments provide an overview of the frequency of and vulnerability to floods. The WHO Collaborating Centre for Research on the Epidemiology of Disasters (CRED) has an Emergency Events Database EM-DAT including an overview of major flood events (EM-DAT 2010 http://www.emdat.be/) and Dartmouth Flood Observatory (http://www.dartmouth.edu/~floods/index.html) also provides information on major flood events. Barredo (2007) provided an overview of major flood disasters in Europe in the period 1950–2005.

The Joint Research Centre (JRC) in Ispra uses the hydrological model LISFLOOD to analyze river discharges across the continent based on the results of simulations under a high emissions scenario (A2) from the regional climate model HIRHAM of the Danish Meteorological Institute. LISFLOOD has been developed for operational flood forecasting at the European scale and is a combination of a grid based water balance model and a one-dimensional hydrodynamic channel flow routing model. Since it is spatially distributed, the model can take account of the spatial variation in land use, soil properties and precipitation. The flooded areas percentages for each larger urban zone was calculated and ingested in the EVDAB database (see annex 7.2).

Components determining sensitivity

Urban population density, asset damage and floodplain extent influences the potential effects of floods (Harvey et al. 2009). The position of buildings or infrastructure systems in relation to the flood is of primary importance. To assess the vulnerability of critical infrastructures, the susceptibility of their function and robustness as well as buffer capacities, replaceability or resilience of the system needs to be assessed (Krings 2010). Birkmann et al. (2010) underlined the importance of evacuation capacity and speed, influenced by household type and walking impairment for the susceptibility of the population. Other components are similar to the ones influencing the sensitivity to heat waves (Tapsell 2002):

1. Age: epidemiological research has shown that above 75 years there is a sharp increase in the incidence and severity of arthritis (and other conditions) and this illness is sensitive to the damp, cold environmental conditions that would follow a flood event.
2. Lone parents: they tend to have less income and must cope singlehandedly with both children and the impact of the flood, with all the stress and trauma that this can bring.
3. Pre-existing health problems: post-flood morbidity (and mortality) is significantly higher when the flood victims suffer from pre-existing health problems (Green et al. 1994).

4. Financial deprivation: The financially deprived are less likely to have home-contents insurance and would therefore have more difficulty in replacing households' items damaged by a flood event (and it would take longer).

Components determining adaptive capacity

Generic indicators for describing the potential for protecting urban regions against floods are GDP, education level and money spent on river flood protection (Harvey et al. 2009). Household income and home ownership can give an indication of available insurance against floods. The past experience with floods also affects the preparedness to future floods (Birkmann et al. 2010). Research indicates that also social class, length of time in residence, and the region in which people live impact significantly the level of flood awareness (Burningham et al. 2008). Fekete (2009) investigated the effects of floods on the affected population in Germany and concluded that

- home owners had more often to leave their home yet less often to seek emergency shelter compared to the average,
- urban residents had more often to leave their home than rural residents,
- many elderly residents had to seek emergency shelter,
- persons with low education background and unemployed people are more dissatisfied with damage regulation.

Other drivers than climate change influencing the issue

Urbanisation (urban sprawl) and associated increases of impermeable land surface coupled with housing and business development of river floodplains exacerbate flood risk in urban areas. Since age and pre-existing health problems influences the reactivity to floods, demographic change will alter the vulnerability to floods.

Fluvial flood related indicators

Name:	**Components influencing vulnerability of urban areas to river flooding**
Source:	**Harvey et al. 2009**
Link:	
Maps:	No
Purpose (thematic, policy):	Raising awareness of river flooding risk across Europe and identifying hotspots for more detailed analysis.
Audience, political level:	Decision-makers responsible for land-use planning, and zoning and implementing the relevant European Directives on flooding
Scale (spatial, temporal):	Spatial: European Temporal: all observed datasets
Components:	Exposure: 1. River flows 2. River floods
	Sensitivity: 3. Current population density
	Adaptive Capacity:

	4. Gross domestic product in Euros/inhabitant 5. Education level: ISCED6 Second stage of tertiary education leading to an advanced research qualification - level 6 (ISCED 1997) 6. Money spend on flood protection from Cohesion fund (REGIONS 2020 report)
Data availability (European, Cities)	1. JRC 2. JRC 3. Eurographics (EU27, NUTS3, unknown current year, no future projections) 4. Eurostat(EU 27, NUTS2, 2002-2006, no future projections) 5. Eurostat (EU 27, NUTS2 and 1, 2004-2006, no future projections) 6. JRC (Regions 2020 report, baseline unknown)
Methods (scaling, standardization, combination):	Suggested to use the methodology of Gornitz (1991) used to form the coastal vulnerability index (CVI) as basis
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes No, no aggregation method is given No, no aggregation method is given Do not know Yes
Limits:	No aggregation methodology, only data availability to form an indicator was analysed. Social (individual) sensitivity components are not included.

Name:	**Remote sensing based vulnerability assessment**
Source:	**Wurm et al. 2010**
Link:	
Maps:	Yes for Cologne and Dresden
Purpose (thematic, policy):	Presentation of remote sensing potential to identify and describe vulnerabilities to floods
Audience, political level:	
Scale (spatial, temporal):	Spatial: 15 m Temporal: current
Components:	Exposure: 1. River flow to calculate dynamic flood mask 2. Digital terrain model
	Sensitivity: 3. 2-D classification of land use 4. 3-D identification of single urban building structures (e.g. single houses, skyscraper) depending on form, height and size of the buildings 5. Population of city districts
	Adaptive Capacity:

	none
Data availability (European, Cities)	1. based on hydrological models 2. based on satellite data 3. based on satellite data 4. based on satellite data (e.g. from IKONOS in 1 m resolution) and aerial photography or laser scanning (e.g. LIDAR) 5. based on census data
Methods (scaling, standardization, combination):	1 + 2 = Flood depths based on a dynamic flood mask and a digital terrain model 3 + 4 = Classification of urban structure types 4 + 5 = Spatial distribution of population data on single buildings depending on housing space (1+2)+(3+4+5) = map of spatial distribution of vulnerable population
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Yes, No, special remote sensing knowledge needed unknown Partly, based on consideration where the highest population densities are to be expected – independent on their sensitivity or adaptive capacity
Limits:	The components describing urban building structure is rather difficult to achieve, but central for the distribution of population and analysis of vulnerability on building level. Social (individual) sensitivity components are not included.

Name:	**Vulnerability of the municipality population to floods**
Source:	**Birkmann et al. 2010**
Link:	
Maps:	Yes for Cologne and Dresden
Purpose (thematic, policy):	Assessment of vulnerability to provide detailed information for flood danger plans, adaptation support and evacuation plans
Audience, political level:	City planning level
Scale (spatial, temporal):	Spatial: City districts Temporal: past data (census data)
Components:	Exposure: 1. Flood threatened area
	Sensitivity: 2. Population in city districts 3. Spatial information about buildings and storeys 4. Type of households (3 different classes depending on age and amount of persons living together)
	Adaptive Capacity: 5. Household income 6. Relation owner vs. lodger

	7. Duration of stay in the flat 8. Expectation about being flooded
Data availability (European, Cities)	1. Flood agency of the city 2. Inhabitant register of the city 3. City agency 4. Inhabitant register of the city 5. Micro census of city Cologne 6. City agency 7. City agency 8. Micro census
Methods (scaling, standardization, combination):	1+2+3 = Population exposed to floods 1+2+4 = Evacuation potential 1+2+4 = Evacuation time needed 1+2+5+6 = Potential insurance protection 1+2+7 = Flood experience 1+2+8 = Flood sensitivity
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Difficult because very specific data is needed No, difficult statistic and derivation of some of the indicators Low, because based on questionnaires and micro census Yes, based on literature review
Limits:	The data collection of the components is very work intensive but based on a detailed of the sensitivity and adaptive capacity indicators. No common aggregation method was suggested.

Name:	**Social susceptibility index in context to river-floods in Germany**
Source:	**Fekete 2009**
Link:	
Maps:	Yes, Elbe and Rhine river valley in Germany
Purpose (thematic, policy):	Generating information about people potentially affected by disasters that are triggered by river-floods by developing and validating a social vulnerability map of population characteristics towards river-floods covering all counties in Germany.
Audience, political level:	experts working on flood protection, regional planners and scientists
Scale (spatial, temporal):	Spatial: county level in Germany
Components:	Exposure: none
	Sensitivity: 1. ratio of elderly residents (>65 years) 2. population density

	3. housing type (one and two family houses, small apartments, rural population)
	Adaptive capacity: 4. living space per person 5. (un)employment ratio 6. education type (Graduates with only elementary education)
Data availability (European, Cities)	Census data of the Federal Statistical Office in Germany (BBR, 2007; Destatis, 2006a)
Methods (scaling, standardization, combination):	The data set was produced after floods impact evidence. The data was first analysed by a component analysis and in a second step validated by analysing an independent second data set with a logistic regression model. The component analysis was used to extract profiles of social groups regarding certain characteristics like income, gender or age that can be linked to a certain extent to measurable variables like building type, urban or rural context, and medical care as a key element of coping capacities. The statistics was used to derive the most sensitive parameters. 1. parameter fragility = function of 1. 2. parameter region = function of 2. and 3. 3. parameter socio-economic conditions = function of 4.,5.,and 6. Index = parameter 1 + parameter 2 + parameter 3
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Yes, but comparable data sets needed which have been derived after a flood No, difficult methodology to derive components which might differ between regions unknown Yes, data set was
Limits:	The data analysis refers to experiences with floods in Germany. It is questionable how far some of the components and their evaluation can be transferred to other regions. Exposure data was not integrated.

Name:	**Social Flood Vulnerability Index (SFVI)**
Source:	**Tapsell et al. 2002**
Link:	
Maps:	Yes: maps of Manchester and Maidenhead
Purpose (thematic, policy):	The index shall measures the impact that floods could have upon the communities potentially affected.
Audience, political level:	City planers
Scale (spatial, temporal):	Spatial: enumeration district (ED) of England and Wales Temporal: past data (1991)
Components:	Exposure: none

	Sensitivity: 1. The long-term sick: residents suffering from limiting long-term illness as a percentage of all residents 2. Single parents: lone parents as a proportion of all residents 3. The elderly: residents aged 75 and over as a percentage of all residents
	Adaptive capacity: 4. Unemployment: unemployed residents aged 16 and over as a percentage of all economically active residents aged over 16 5. Overcrowding: households with more than one person per room as a percentage of all households. 6. Non-car ownership: households with no car as a percentage of all households 7. Non-home ownership: households not owning their own home
Data availability (European, Cities)	1991 census data from the Manchester Information and Associated Services (MIMAS), being available for England and Wales at the level of the enumeration district (ED)
Methods (scaling, standardization, combination):	The data was transformed to reduce skewness and kurtosis, afterwards the data were standardized as Z-scores and then summed (the indicators for financial deprivation were summed separately and then multiplied by 0.25 prior to their inclusion in the index). (4. +5. +6. +7.)*0.25 = 8. financial deprivation 1. +2. +3. +8. = index The index was classified in 5 bands.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Yes Yes ? Yes
Limits:	Simple indicator with old data and without integration of exposure information.

Name:	**Integrated urban flood risk assessment**
Source:	**Meyer et al. 2009, Kubal et al. 2009**
Link:	
Maps:	Yes: Leipzig
Purpose (thematic, policy):	
Audience, political level:	Science
Scale (spatial, temporal):	Spatial: Leipzig (10 m*10 m), individual houses
Components:	Exposure: 1. Depth of inundation (data from four flood events with different recurrence

	probabilities provided by the Saxon Water and Flood Management Authority (1/50 = recurrence probability in 50 years, 1/100, 1/200, 1/500)
	Sensitivity: 1. Land use 2. Classification of buildings (e.g. Town Center, Terrace houses, Council houses) to estimate building height 3. Land values (prices) 4. Affected (total) population (excluding children and the elderly) per building 5. Number of children 0-10 yrs per residential house 6. Number of elderly people > 65 yrs per residential house 7. Number of social hot spots (Social infrastructure such as schools, hospitals, kindergartens, pensioners' homes, etc.) 8. potential contamination (contaminated sites) 9. soil erodibility (non-sealed surfaces with erosion potential) 10. abundance of oligotrophic biotopes (Peat bogs, heath etc.) 11. vulnerable protected biotopes (Semi-arid grasslands, poor marsh areas, etc.) 12. vulnerable trees with low withstanding against long-term inundation.
	Adaptive Capacity: none
Data availability (European, Cities)	Data for Leipzig was from municipal statistics (census and social data of the City of Leipzig for 2006 and 2007) or urban planning agencies (land values).
Methods (scaling, standardization, combination):	The multi criteria assessment tool by Meyer et al. (2009) was used to process the data that have been put together in a Geographical Information Systems (GIS). It was further processed using the software FloodCalc. 7 to calculate risks: 1. risk = Aggregated economic risk: based on 1. + 2. (land use-type elements of risk: transport, residential buildings (including height), industrial and commercial areas, administration and service, sport and recreation and garden allotments) 2. risk = Land values: based on 1., 2. , 3. 3., 4., 5., 6. risk = social risks 7. risk = Aggregated ecological risk: based on 8. +9. +10. +11. +12. The components were weighted by a binary code (presence or absence in the inundation area), except population related components to calculate the risks. The risks were standardized and weighted in different scenarios differently.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Yes No ? Yes
Limits:	Interesting method of weighting and combining the components and risks, data only available at city scale. Economic and ecologic risks are not considered in other risk assessments.

Name:	**Social vulnerability indicators for flood risks**
Source:	**Aleksandra Kazmierczak, personal communication** **paper in preparation**
Link:	
Maps:	unknown
Purpose (thematic, policy):	unknown
Audience, political level:	unknown
Scale (spatial, temporal):	Spatial: City of Manchester, resolution in hectare Temporal: unknown
Components:	Exposure: 1. Flood risk areas and land use
	Sensitivity: 2. overcrowded households 3. people with limiting long-term illness 4. people whose health was not good 5. households with at least 1 person with a limiting long term illness 6. children under 4 years old in the population 7. people 5 to 17 years old in the population 8. households with dependent children 5-18 years old 9. households with dependent children under 4 years old 10. households with no adults in employment and dependent children 11. households with no adults in employment (no children) 12. people deprived in terms of their income 13. people deprived in terms of their employment 14. households with no car 15. unemployed among economically active 16 - 74 years old people 16. people with no or level 1 qualifications 17. people born outside the GB 18. ethnic minorities 19. people aged over 75 in the population 20. people aged 65 to 75 in the population 21. all pensioner households 22. single pensioner households 23. single person households (non-pensioner) 24. lone parent households with dependent children 25. households rented from social landlords 26. households rented from private landlords 27. residents living in residential care
	Adaptive Capacity: Included in sensitivity components
Data availability (European,	Census data on number of people per hectare in %

Cities)	
Methods (scaling, standardization, combination):	The choice of indicators was based on literature review. Then, the spatial distribution of all components was presented, and its associations with the distribution of flood risk areas and different types of land use and housing affecting exposure were analysed. Principal component analysis was used to reduce the components to 4 components (poverty and poor health; ethnic minority and transient populations in high density housing; families with dependent children; elderly populations). The values of individual principal components were not combined into an index, as the knowledge about the character of vulnerability (e.g. due to elderly population) can help to choose and target the adaptation responses better.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	Not possible, because only limited information available. The paper will be published next year.
Limits:	Information on how flood risk areas are defined and whether future climate projections are used is not available yet.

Name:	**Social vulnerability indicators for flood risks**
Source:	**Ebert and Müller 2010**, further paper with details on indicator development in preparation
Link:	
Maps:	
Purpose (thematic, policy):	Raising awareness for (a) the issue of vulnerability and (b) the complexity of relevant variables and their interaction/interrelations and providing a decision making aid for planers and emergency managers.
Audience, political level:	Planers at municipality to city level
Scale (spatial, temporal):	Spatial: Building blocks in two municipalities within the city of Santiago de Chile, Chile Temporal: 2002 census data was used, GIS and remote sensing from different times
Components:	Exposure: none
	Sensitivity: 1. Quality of building material 2. Household size related to bedrooms 3. Age (below 5, above 65 yrs old) 4. Rate of females 5. Green areas 6. Rate of building parts below street level

	Adaptive Capacity: 7. Unemployment rate 8. Rate of population without income 9. Education level
Data availability (European, Cities)	Census data (by Instituto Nacional de Estadisticas de Chile, 2002), GIS and remote sensing data.
Methods (scaling, standardization, combination):	The components were standardised per building block, weighted based on expert and household opinion and summarized.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes yes yes Partly good (GIS, remote sensing), partly unknown (Census) Yes (selection and weights based on literature review and expert interviews)
Limits:	Some of the indicators need to be adapted to European conditions. Exposure data needs to be integrated. The GIS methodology for graphical presentation of the data is very useful.

Name:	**Spatial vulnerability units for socio-economic flood modelling**
Source:	**Kienberger et al. 2009**
Link:	http://www.nat-hazards-earth-syst-sci.net/9/767/2009/nhess-9-767-2009.pdf
Maps:	Yes: vulnerability, sensitivity and adaptive capacity units in the Salzach Basin
Purpose (thematic, policy):	This paper discusses a spatial explicit model for assessing socio-economic vulnerability to flood hazards at the sub-national level and independent from administrative boundaries.
Audience, political level:	unclear
Scale (spatial, temporal):	Spatial: Sub-national level, independent from administrative boundaries, example used: Salzach river catchment including the city of Salzburg in 100 m grid cell solution, Temporal: 2001
Components:	Exposure: none
	Sensitivity: 1. Number of buildings per grid cell with different households size and building uses 2. Infrastructure length per grid cell (roads, railways, power plants, etc.) 3. Assets per grid cell (crops, pasture, forests, springs, etc.) 4. Sensitive land covers per grid cell (alpine meadows, lakes, glaciers, etc.) 5. Age distribution of population (<20, 20-80, > 80 yrs)

	6. Employment rates of population
	Adaptive Capacity: 7. Workforce in different economy sectors 8. Size of companies/workplaces 9. Ecosystem integrity of sensitive areas 10. Distance to health facilities and roads 11. Early warning system available 12. Origin of population 13. Education level
Data availability (European, Cities)	Data from the census survey in 2001, provided by Government of Salzburg through its public GIS database.
Methods (scaling, standardization, combination):	Appropriate indicator datasets have been selected with the help of expert knowledge depended on data availability and coverage. For integrating the different indicator data and to aggregate them on a sub-domain level, Multi Criteria Analysis (MCA), Multi Criteria Evaluation or Analytical Hierarchy Process (AHP) were applied. To allow the integration and comparison of different data sets and data sources normalization was applied. The different indicator data sets were integrated on a domain level through weighted linear combination. Therefore the raster datasets are multiplied by a weight and finally summed up. The weights have been derived from a scoring exercise with stakeholders and experts.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No (except scientific purpose) Yes No Partly (census data) Yes: literature, experts and stakeholders have been involved
Limits:	Interesting and well described methodology to use homogenous vulnerability units, but much socio-economic and bio-physical data is needed. Exposure data needs to be integrated (digital terrain model, river flows). Interpretation difficult because weightings bias population density. Also adaptive capacity and sensitivity data does not directly outcompete each other, thus areas with high adaptive capacity can be the ones with high vulnerability.

7.1.6 Intensive precipitation and urban drainage floods

Effects

Local intense precipitation can cause overflows from and damage to drainage infrastructure that has been designed to accommodate lower flows based on historical rainfall records and urbanisation levels. These events create high peak storm water flows that cause erosion and sedimentation when discharged to natural surface water bodies. Possible consequences of intensive rainfalls include flooding (surface flooding, flooding of house basements or other underground structures), sewer surcharge and combined sewer overflow (Nie et al. 2009). Several municipalities have reported frequent and severe flood damage and combined sewer overflows in the last decade. Several projects have investigated the potential impacts on climate change on urban flooding (see Nie et al. 2009 for an overview).

Components determining exposure

Increasing rainfall intensities.

Components determining sensitivity

Enlargement of impervious urban surfaces in combination with under-designed urban drainage systems create challenges for the urban drainage. Impermeable (built-up) areas increase the runoff water, overcrowding the sewage and drainage system and putting pressure on the availability of groundwater (Nie et al. 2009). The topography of a location influences sensitivity of a city to urban drainage: Settlement areas located at or below slopes, especially when the areas above are highly impermeable areas, can be flooded by drainage overflow water. Settlements in depressions are most sensitive such as areas prone to subsidence, e.g. due to mining activities (Steinrücke et al. 2010). Also the type of the drainage system plays a role: In combined sewer systems (where domestic and industrial waste is mixed with storm water) intense precipitation reduces the effectiveness of the wastewater treatment process. Overflows from this system result in untreated sewage being discharged to the environment.

Components determining adaptive capacity

The condition of the permeable surface (with or without vegetation, wet or dry, porous or compacted) influences the infiltration capacity of the soil. Small urban creeks, which are used to drain a settlement, might be surcharged by heavy precipitation events followed by an overload and backwater in the storm-water drainage system. Their drainage capacity depends on the existence of flood control measures, the occurrence of shallow bridges or other structures decreasing their cross sectional areas and the potential to transport sediment. The condition of the drainage system influences its drainage capacity: e.g. drainage systems which work by gravity are much more sensitive to downstream receiving water levels than system with pumps. Also the availability of temporary storm-water retention areas or “emergency water ways” is important to reduce the occurrence of urban drainage floods (Hasse 2010).

Other drivers than climate change influencing the issue

Urban sprawl and urbanization will lead to enlarged impervious surfaces in catchments, increasing therefore the need to collect and infiltrate rainwater.

Urban drainage flood related vulnerability indicators

Name:	**Vulnerability indicators for extreme rainfall and storm water management**
Source:	**Preston et al. 2008**
Link:	http://www.csiro.au/resources/SydneyClimateChangeCoastalVulnerability.html
Maps:	Yes: vulnerability to extreme rainfall in the Sydney Coastal Councils Groups region
Purpose (thematic, policy):	Part of a wider study with the aim to assess the potential biophysical effects of climate change including examining local adaptive capacities. The vulnerability maps shall be used to initiate a dialogue among researchers and stakeholders

	and a bottom-up assessment of local governments.
Audience, political level:	Researchers, stakeholders, local government
Scale (spatial, temporal):	Spatial. A spatially homogenous data scale of a 90 metre grid was used Temporal: current data used, except 2019 for population projections and 2030 for climate projections
Components:	Exposure (Climate): 4. Average rainfall (present annual average) 5. Rainfall variability (present average annual 90th percentile) 6. Projected rainfall (projected changes in extreme rainfall events in 2030)
	Biophysical Sensitivity: 7. Land Cover (Land use, Vegetation cover, annual primary production) 8. Topography (slope, aspect) 9. Soil (drainage, average soil water holding capacity) Socio-economic Sensitivity: 9. Population (population and road density, projected population growth to 2019)
	Economic Adaptive Capacity: 10. Access to technology (households with internet access) 11. Financing (Median home loan repayment, home ownership, household income, households requiring financial assistance) 12. Education (>12 yrs) 13. Human Resources (non-English speaker) Social Adaptive Capacity: 14. Responsibility (council current ratios, per capita business rates, per capita residential rates, per capita community service expenses)
Data availability (European, Cities)	
Methods (scaling, standardization, combination):	Differentiation between bio-physical and social/ecological vulnerability. A simple conceptual model was used to structure components based on the three elements of vulnerability which were further differentiated into biophysical and socio-economical sensitivity, economic and social adaptive capacity. For each element (exposure, sensitivity and adaptive capacity) a data layer was created by a sum of the components, sums were rescored to a scaled from 1 to 9 based upon quintiles. The three data layers were integrated by summation the scores after weighting them due to expert judgement (0,5 ; 1; 2, adaptive capacity was given the weight 0,5), the result again being rescored.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Partly (method to aggregate components not completely explained, expert judgement on weights of vulnerability elements difficult) No, because many data needs for adaptive capacity which is only marginally weighted Unknown (census data)

	Yes
Limits:	Adaptive capacity components based mainly on economic data, although wider conceptual approach was wanted. The aggregation of the components for one element layer is unclear.

7.1.7 Sea level rise and storm surge-driven flooding

Effects

Direct impacts from sea level rise include an additional pressure on coastal defences and higher chances on inundation and displacement due to storm flooding, increased coastal erosion, increased salinity in estuaries and coastal aquifers, and rising coastal water tables and impeded drainage (EEA 2008, Torresan 2008). Potential indirect impacts include changes in the distribution of bottom sediments, changes in the functions and diversity of coastal ecosystems and impacts on human activities. Storm surges can accelerate coastal erosion, loss of property and land and the loss of human life, and where major urban areas are located on the coast, disruption to transport and communications can affect the whole country for weeks afterwards (IPCC 2007).

Projected changes in climate that are relevant for the population and economy of coastal zones are sea level rise, changes in water temperature, the direction and the power of waves and a possible increase in extreme weather events. Assessment of economic and human vulnerability to climate change in coastal zones focuses primarily on sea level rise and storm surges. Many parts of European coastline (e.g. North Sea region, Baltic Sea, Mediterranean and Black Sea), where major cities and economic centres are located (Harvey et al. 2009), are prone to suffer from higher water levels and storm surges (EC DG Mare 2009, IPCC 2007). Other significant pressures that might become a burden for European coastal zones are related to increasing population concentrations and subsequent economic activity. These pressures will interact with climate change and exacerbate or ameliorate vulnerability to climate change (EEA 2006).

The potential impacts on human and economic systems can be significant, especially due to increased flood risk and storm damage in low-lying areas. Next to intertidal habitats and ecosystems also coastal cities and communities are threatened. The actual impacts of climate change are highly uncertain (IPCC 2007) but success in human adaptation to that change and appropriate proactive measures could help avoid or manage effectively many of the impacts.

Components determining exposure

Global mean sea-level is projected to rise by 0.18m to 0.59m or up to 1 or 2 m by 2100 (IPCC 2007, UNEP 2009). Storm water flooding in coastal urban areas can occur during storm surges when there are temporary increases in sea level above the normal tidal range (EEA 2008). Future modelled projections indicate a slight decrease in the number of storms, but an increase of the strength of the heaviest storms, and projections to the end of the 21st century show a significant increase in storm surge elevation for the continental North Sea and south-east England (EEA 2008). Storm surge destruction is often greatest near the shore, while wind damage is far more extensive (Lewis 1990).

Components determining sensitivity

The coastal system, its inhabitants and their economy are sensitive to sea level rise and surge driven flooding depending on geographic position and biophysical components such as changes in water depth influencing tidal patterns, the relative influence of isostatic movement, the elevation of the land, the morphology of the coast, the location, height and maintenance of sea defences, etc. (Barredo et al. 2008). On the basis of these components sensitivity to sea level rise will differ strongly along the European coast. The lower delta regions, traditionally the home of many people, but also wetlands and river mouths are most vulnerable (Harvey et al. 2009). Also small cities and towns located entirely upon barrier islands may be particularly vulnerable to extensive loss, with virtually all their buildings being severely damaged or destroyed (Lewis 1990).

Data on population density will be needed to determine the amount of people exposed to flood risk. Although the increase in sea level during a storm surge may be temporary, the urban flooding episodes can last much longer depending on the ability of the urban area to drain the excess flood-water which is influenced by the size of storm water drains and the extent of non-permeable land Also social components such as property values and other economic assets in exposed areas will influence the relative vulnerability of different locations and could include the degree and level of protection afforded to urban coastal areas, the degree of urban development and levels of investment in flood defence (Harvey et al. 2009).

Components determining adaptive capacity

The economic resources and the institutional capacity of coastal regions as well as the knowledge and awareness of the inhabitants, e.g. measured by the money spent on sea defences, can be used to indicate the adaptive capacity of human systems in the coastal regions to sea level rise (EC DG Mare 2009).

Other drivers than climate change influencing the issue

Increasing human-induces pressures on coasts (e.g. growing population, land use changes and urbanization) as well as increase in material wellbeing will influence the vulnerability to flooding in coastal urban areas (Torresan et al. 2008).

Sea level rise related indicators

Name:	**Components influencing the vulnerability of urban coastal areas to storm surge-driven flooding**[30]
Source:	**Harvey et al. 2009**
Link:	
Maps:	No
Purpose (thematic, policy):	Demonstration of the vulnerability of coastal areas across Europe to the impacts of rising sea levels and in particular storm surge events for raising awareness of the potential increase in flooding events based on current levels of protection.
Audience, political level:	Depends on specific purpose
Scale (spatial, temporal):	Spatial: European to city level Temporal: mainly past data, except sea level rise and people flooded (2080, A2)

[30] This is not a real indicator – in other words only developed to demonstrate a process rather than to be used for policy. However, the data sources are probably relevant.

Components:	Exposure: 1. Sea level rise projection (mm/yr) 2. Storm surge: change in height of 50 year return extreme water level event Sensitivity: 3. Current and projected number of people flooded across Europe's coastal areas (thousand/year) 4. Current population density 5. Elevation and slope 6. Coverage of sea defences in Europe Adaptive Capacity: 7. Gross domestic product in Euros/inhabitant 8. Education level: ISCED6 Second stage of tertiary education leading to an advanced research qualification - level 6 (ISCED 1997)
Data availability (spatial extent, resolution, past time series, future projections)	1. EEA (in progress: NW Europe, 100 km spaced points, ?, annual increases) 2. Lowe and Gregory, 2005*(unknown) 3. JRC (in progress: unknown, unkown, 1961-1990, 2080 (A2)) 4. Eurographics (EU27, NUTS3, unknown, unknown) 5. USGS (EU27, 0.0833 DECIMAL DEGREES, unknown, unknown) 6. EEA (unknown)[31] 7. Eurostat (EU 27, NUTS2, 2002-2006, no future projections) 8. Eurostat (EU 27, NUTS2 and 1, 2004-2006, no future projections)
Methods (scaling, standardization, combination):	Not suggested
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes, but not the audience No, no aggregation method is given No, no aggregation method is given Unknown Yes
Limits:	No aggregation methodology, only data availability to form an indicator was analysed.

Name:	**Indicators for coastal vulnerability assessment at the regional scale**
Source:	**Torresan et al. 2008**
Link:	
Maps:	Yes, Veneto area maps for different components

[31] Harvey et al. 2009: National databases on sea level defences, their height, lifespan and maintenance programmes do exist, for example in the UK, but collection of this data at the EU level would be needed to supply information for the other variables mentioned above.

Purpose (thematic, policy):	Set of coastal vulnerability indicators at the regional scale to understand and manage the complexities of a specific study area, to cope with a range of climate-change related issues in the medium and long term.
Audience, political level:	Decision makers at the local and regional scale
Scale (spatial, temporal):	Spatial: regional scale Temporal: past data
Components:	Exposure: none
	Sensitivity: 1. Administrative units 2. Location of Primary Italian rivers 3. Geomorphological characteristics/coastal typologies (open coast sandy shores, open muddy shores, open clayey-gravel shores, open slump-prone shores, sandy barriers and spits, open/exposed hard-rock cliffed shores) 4. Wetland migratory potential WMP (morphological response of coastal landforms and ecosystems to seal-level rise) 5. Coastal population density
	Adaptive capacity: none
Data availability (European, Cities)	Topograhic, geomorphological and geological maps and data sets of Italian authorities, and Image and Corine land Cover dataset (2000), Italian census data
Methods (scaling, standardization, combination):	The coastline was classified in reasonably homogeneous segments (such as in the DIVA approach) characterized by the same attributes for each components in each unit. The procedure was map intersection and overlay using GIS.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Yes The GIS procedure is rather simple, but the data provision difficult High Based on the DIVA approach, but simplified due to data constrains
Limits:	The results of the procedure are "spatial homogenious sensitivity units", which do not allow a comparative assessment of the different units. Exposure and adaptive capacity components are not considered.

Name:	**Coastal sensitivity index (CSI)**
Source:	**Abuodha and Woodroffe 2010**
Link:	
Maps:	Yes, for the Illawarra coast (Australia): maps of specific components and the indices
Purpose	A coastal sensitivity index to characterise susceptibility was assessed.

(thematic, policy):	
Audience, political level:	Unknown
Scale (spatial, temporal):	Spatial: 155 km coastline, with raster cells of 1.5 km by 1.5 km Temporal: Past data on exposure components, current data for sensitivity components
Components:	Exposure 1. Relative sea level rise 2. Mean wave height 3. Mean tidal range
	Sensitivity: 4. Rock type 5. Coastal slope 6. Geomorphology 7. Barrier type 8. Shoreline exposure 9. Shoreline change (historical trend of shoreline movement)
	Adaptive Capacity: none
Data availability (European, Cities)	Tide gauge records for exposure data, Orthorectified aerial photography, GPS data, fieldwork for sensitivity data,
Methods (scaling, standardization, combination):	The variables were classified and semi-qualitatively ranked in 5 groups according to their assumed sensitivity (very low to very high). An index is derived by determining the square root of the products of the ranked variables divided by the total number of variables. The variables were not weighted. Four indices were calculated with different combinations of variables.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 No Yes Yes, except data provision Unknown Yes, mainly conventional variables used based on literature review, ranking based on expert knowledge
Limits:	No relation to urban areas, only physical sensitivity components are included. The ranking enables a comparison of different regions. The reasons for the ranking were discussed

Name:	**Physical and social vulnerability to sea level rise and storm-surge flooding**
Source:	**Kleinosky et al. 2006**
Link:	
Maps:	Yes, for physical, social and overall vulnerability of Hampton Roads
Purpose	This paper uses Hampton Roads, a metropolitan region of 10 cities and six

(thematic, policy):	counties in southeastern Virginia, as a case study to understand how sea-level rise will increase the vulnerability of people and infrastructure to hurricane storm surge flooding over the next century.
Audience, political level:	Local planners should account for the storm-surge zones when considering future development in Hampton Roads, paying special attention to the placement of critical facilities and of housing for poor, elderly, and other vulnerable people.
Scale (spatial, temporal):	Spatial: Hampton Roads, elevation data in 10-30 m², social data in km² Temporal: current and future (2100 + 30,60 or 90 cm SLR) physical vulnerability, past (2000) social vulnerability data as well as projections of population growth and scenarios of distribution pattern (2100) was used
Components:	Exposure 1. MEOW (Maximum Envelopes of Water) as maximum surge height in a cell for a given hurricane category and storm track 2. MOM (Maximum of MEOWs) represents the maximum surge height in each cell for hurricanes of a particular Saffir–Simpson category, regardless of storm track or direction
	Sensitivity 3. Elevation 4. Immigrant component (including new immigrants, Asians, people of two or more races, people of some ‘‘other’’ race, non-English speakers 5. Old age/disabilities component (including old people, people with disabilities (all types)) 6. Spatial distribution of critical facilities such as schools, hospitals, and fire and rescue departments that are crucial to the everyday functioning of a community. 7. Population growth projections and population distribution scenarios
	Adaptive Capacity 8. Poverty component (including young people, old people, adults without high school diplomas, people living in poverty, people dependent on public transit, single-mother households, renters, housing units without telephones, housing units without vehicles, per capita incomes, median earnings, median household incomes, median housing values)
Data availability (European, Cities)	1.+2. data from the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model of the National Hurricane Center, which is also used for coastal hurricane evacuation plans. 3. Digital Elevation Model of the US Geological Survey 4. – 6. + 8.United States Census data of 2000 7. National Planning Association Data Services) until 2050, linearly extended until 2100
Methods (scaling, standardization, combination):	Physical vulnerability: The results of the SLOSH model were compared with the elevation data (areas at risk of flooding from Category 1 hurricanes were given the highest score, while areas not at risk of flooding from even Category 5 hurricanes were given the lowest score). Social vulnerability: Based on the former work of Kleinosky, 57 variables describing poverty, gender, race and ethnicity, age, and disabilities were used in

	a principal components analysis to derive 3 components for poverty, immigrants, and old age/disabilities. Densities were calculated per square kilometres and related to 1027 blocks groups. The components were displayed in four equal-interval classes. To combine the 3 components, Pareto ranking was used to organize the block groups into 19 ranks. Alternatively the spatial distribution of critical facilities was used to describe current social vulnerability. For estimating, future social vulnerability the three population distribution scenarios were used. To assess overall vulnerability, physical vulnerability scores were multiplied by social vulnerability scores, and the result was sorted in 4 equal-interval classes.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Limited, access to storm-surge model and statistical analysis are needed No (extensive social vulnerability data needed) Unknown (census data) Yes, but relation of social components to vulnerability unclear
Limits:	Differentiation in social and physical vulnerability is good, but difficult methods for both (storm-surge model and statistical analysis of social data) and simplified aggregation of social and physical vulnerability. Adaptive capacity was not explicitly included (merged into the social vulnerability components). The alternative approach of using the distribution of critical facilities as measure of social vulnerability is interesting.

Name:	**Vulnerability Indicators for Sea-Level Rise and Coastal Management**
Source:	**Preston et al. 2008**
Link:	http://www.csiro.au/resources/SydneyClimateChangeCoastalVulnerability.html
Maps:	Yes: vulnerability to sea level rise in the Sydney Coastal Councils Groups region
Purpose (thematic, policy):	Part of a wider study with the aim to assess the potential biophysical effects of climate change including examining local adaptive capacities. The vulnerability maps shall be used to initiate a dialogue among researchers and stakeholders and a bottom-up assessment of local governments.
Audience, political level:	Researchers, stakeholders, local government
Scale (spatial, temporal):	Spatial. A spatially homogenous data scale of a 90 metre grid was used Temporal: current data used, except 2019 for population projections
Components:	Exposure (Climate): 1. Present relative storm surge
	Biophysical Sensitivity: 2. Topography (Distance to coastline, defined sensitive coastal locations, elevation, slope) Socio-economic Sensitivity: 3. Land cover (land use, vegetation cover) 4. Population (density, road density, projected population grow to 2019, acid sulphate soils)
	Economic Adaptive Capacity:

	5. Access to technology (households with internet access) 6. Financing (Median home loan repayment, home ownership, household income, households requiring financial assistance,) 7. Education (>12 yrs education) 8. Human Resources (non-English speaker) Social Adaptive Capacity: 9. Responsibility (council current ratios, per capita community service expenses, per capita business rates, per capita residential rates) 10. Leadership (?) 11. Community (?) 12. Priority (?) 13. Equity (?)
Data availability (European, Cities)	
Methods (scaling, standardization, combination):	Differentiation between bio-physical and social/ecological vulnerability. A simple conceptual model was used to structure components based on the three elements of vulnerability which were further differentiated into biophysical and socio-economical sensitivity, economic and social adaptive capacity. For each element (exposure (1-2), sensitivity (3+4) and adaptive capacity (5-13)) a data layer was created by a sum of the components, sums were rescored to a scaled from 1 to 9 based upon quintiles. The three data layers were integrated by summation the scores after weighting them due to expert judgement (0,5 ; 1;2, adaptive capacity was given the weight 0,5), the result again being rescored.
Interpretation Clear purpose: Reproducibility: Simplicity: Data reliability: Knowledge based:	 Yes Partly (method to aggregate components not completely explained, expert judgement on weights of vulnerability elements difficult) No, because many data needs for adaptive capacity which is only marginally weighted Unknown (census data)
Limits:	Only present storm surge data was used. Adaptive capacity components based mainly on economic data, although wider conceptual approach was wanted. The aggregation of the components for one element layer is unclear (adding without normalisation except elevation and acid soils).

Source and name of the composite indicator	**Scale/ Hazard**	**Sub indicators /Components**	**Method**
Torressan et al. (2008): Subset of coastal parameters included in the	Global scale/ sea-level rise	**Sensitivity**: 1. Area at specific elevation 2. Coastal slope 3. Coastal plains (glacial, fluvial, dune, destructive, coral and non-plain)	Map intersection and overlay to determine homogenous segments.

DIVA database to assess coastal vulnerability		4. Wetland types (forested, fresh water marsh, high unvegetated, low unvegetated, saltmarsh) 5. Wetland migratory potential 6. Coastal population 7. Coastal population density	
Gornitz et al. (1991): Coastal Vulnerability Index (CVI) to identify areas at risk of erosion and/or extreme climatic events	Regional scale/ sea-level rise	**Exposure**: 1. average wave heigth, 2. relative sea-level change tax, 3. average tidal range **Sensitivity**: 4. geology resistance, 5. erosion tax (tendencies of long term changes in the coastline), 6. coastal slope	Coastal topography is calculated trough the arithmetic mean of three parameters: height, slope and area. The mean value for each parameter is extracted from cells under 10 meters height of the DEM, by drawing polygons (200 meters wide) perpendicular to the shoreline. The variables were classified and semi-qualitatively ranked in 4 classes according to their assumed sensitivity. An index is derived by determining the square root of the products of the ranked variables divided by the total number of variables.
Ecological and Socio-economic Vulnerability Indices for Andalusia (Andalusia, in preparation)[32]	Regional scale/ sea-level rise	**Exposure**: 1. Height (DEM) 2. Distance to the shoreline with connectivity **Sensitivity**: 3. Biocenotic diversity index (as sum of the structural diversity (number of plant strata), and diversity of habitats) 4. Outstanding natural values index (dependent on existence of a natural protected area and its level of protection) 5. Residential uses (weighted by their potential population) 6. urban uses (weighted by their potential socio-economic worth) 7. Agricultural land uses (weighted by their socio-economic worth) 8. Heritage (weighted by its level of protection)	Height is weighted by its inverse squared. Distance to the shoreline is classified in 5 ranks, and then a weighted value is assigned to each class (1, 2, 4, 8, 16). Exposure is derived from the product of weighted height and distance to the shoreline. The sensitivity indices are multiplied by exposure for the final index values (for areas perpendicular to shoreline below 10 m height and 200 m wide). **Still working on integration of indices**.

[32] Contact: Jose Álvarez, Universidad de Sevilla, jalvarez2@us.es.

Additional literature which was not analysed because of time constrains:

Pethick, J.S. and S. Crooks (2000). Development of a coastal vulnerability index: a geomorphological perspective. Environmental Conservation, 27(4), pp. 359-367 Cambridge University Press, [http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=74373]

Cooper, J.A.G., McLaughlin, S. (1998). Contemporary multidisciplinary approaches to coastal classification and environmental risk analysis. Journal of Coastal Research 14(2), pp. 512-524.

Titus, J.G. and Richman, C. (2001). Maps of lands vulnerable to sea level rise: modelled elevations along the US Atlantic and Gulf coasts. Climate Research 18, pp. 205-228.

Thieler, E.R., Williams, J., and Hammar-Klose, E. (2000). National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast. U.S. Geological Survey, Open-File Report 99-593, Woods Hole, USA.

7.1.8 Saltwater intrusion into aquifers

Effects

In coastal areas, overexploitation of groundwater resources can disturbed the naturally established equilibrium between seawater and freshwater resulting in uncontrolled saltwater encroachment into coastal aquifers (Darnault and Godinez 2008). Salt intrusion is an issue for all European coastal areas that make use of coastal aquifers, however, those that are already short of water during the warmest month, the Mediterranean and Black Sea, are most vulnerable (BSC 2008, Timms et al. 2008). As a large portion of the European population lives in coastal areas, climate change can have an accelerating adverse effect on water availability, especially in combination with mismanagement and overexploitation (Timms et al. 2008).

Components determining exposure

Possible impacts of sea level rise on coastal water resources can be significant, especially in combination with storm surges and the risk of inundation of coastal zones. Shoreline retreat leads to a hydrological altered situation and salt intrusion in the outer layer of a freshwater lens and subsequent decrease of freshwater volume. The strength of coastal defences determines sand dunes reduction and shoreline retreat along the aquifers coastline. River bed elevation due to a higher sea level can cause saltwater intrusion in aquifers adjacent to rivers (Darnault and Godinez 2008).

Components determining sensitivity

Population density in combination with the exploitation of coastal aquifer system(s) and local/regional water availability from other sources are important components determining sensitivity of human populations to salt intrusion. Most coastal aquifers suffer from urbanisation resulting in coverage of large surface areas by concrete and asphalt and a significant reduction in natural recharge (Bear 2004). The degree to which coastal aquifers are incorporated in an efficient hydrological management as well as geology, soil and crop characteristics are important components determining also sensitivity (Salama et al. 1998).

Components determining adaptive capacity

Efficient management strategies are needed for optimal and sustainable water withdrawals from coastal aquifers, while maintaining salt concentration under specific limits. Following issues are relevant when determining adaptive capacity (Maimone et al. 2004):

- For existing wells: can the pumping rate be decreased and regulated to a new maximum extraction when the hydrological balance demands this?
- For new wells: can they compensate for the loss of pumping rate of the existing wells?
- Are there opportunities to increase the natural groundwater recharge with for example the use injected recycled water or canals?

Other drivers than climate change influencing the issue

Urbanisation, demographic change and future water use behaviour will have an effect on water demand in coastal areas.

7.1.9 Mass movements and erosion

Effects

Mass movements include processes such as rock-, block- and ice fall, rock- and block avalanches, spontaneous and continuous landslides, unconfined debris flows, subsidence, sinkholes (Kunz and Hurni 2008). In general, mass movements are processes in which solid material (stone or loose rock) is set in downward motion mainly by gravity, and without the assistance of a transport medium (e.g. snow, water, wind). Water is often involved in the initiation and progress of the process, especially with debris flow and landslides. Mass movements can occur suddenly (e.g. rockfall) or as slow and continuous processes (e.g. deep creep and continuous sliding motion). The origination, progress and effects of mass movements are extremely varied[33]. Heavy precipitation, also connected with flooding, can cause intensive soil erosion and mass movements followed by damages to infrastructures systems (transport systems, buildings, etc.). In high mountain regions such as the Alps, decreased permafrost can be followed by more landslides with substantial potential impact on transportation infrastructure (roads, railways, cable cars) and economic sectors such as tourism (EEA 2008). In addition, glacier retreat leaves unconsolidated moraine material that is susceptible to enhanced erosion and debris flows. However, the direct threat for cities seems to be little.

Components determining exposure

The expected warmer and more humid winter could increase the hazard of mass movements, as water is the important factor in moving masses, e.g. unconfined debris flows as well as landslides are normally triggered by intense precipitation[33]. Intensity, duration and frequency of precipitation events influence also the soil erosion risk. A temperature increase will increase the risk of permafrost and glacier reduction, which has a negative effect on slope stability.

[33] Planat- Natural hazards in Switzerland, http://www.planat.ch/index.php?userhash=134441866&nav=4,476,476,476&l=e

Components determining sensitivity

The relationship between mass movements or soil erosion and climate change is complex and still not well understood (EEA 2008). A precondition of mass movement is the instability of slopes or parts of these. The origination and progress of mass movements are influenced by several factors that are interrelated in a complex way. Significant factors are, for example, geological structure (loci of bedding planes, fissures, etc.), soil and rock characteristics and slope inclination. Geologically unfavourable regions are particularly affected by mass movements, when flysch, molasse, alpine slate or fine-grained debris are dominant[33].

Components determining adaptive capacity

Ground cover and canopy cover decrease soil erosion (IPCC 2007). Measures increasing soil permeability will reduce the erosion risk. Hazard-prone areas should be avoided. Some structural measures, such as training dikes, or wedge-shaped structures above buildings, divert the debris flows.

Other drivers than climate change influencing the issue

Urbanisation decreases the permeability of the soil, leading thus to an increased risk of flooding and soil erosion.

Mass movements related hazard maps

The goal of hazard maps is to protect people and buildings by indicating dangerous areas. The method for the development of hazard maps in Alpine countries varies by country. In the case of Switzerland, intensities of possible hazardous events are assessed by the consultation of past events, current conditions, numerical and physical models and expert judgment (Kunz and Hurni 2008). Similar approaches are taken in Austria and Italy. Also German hazard maps shall not only include areas where mass movements have been experienced but also areas where such events can occur[34].

Further reading:

Tate E., Cutter S.L., Berry M.(2010). Integrated multihazard mapping. Environment and Planning B: Planning and Design 37(4), pp. 646 - 663.

Rød, J. K. Berthling, I., Lein, H., Lujala, P., Vatne, G. (2010). Mapping Climate Change, Natural Hazards and the Vulnerability of Districts in Central Norway. Presentation at the Climate and Security workshop, Trondheim. [http://climsec.prio.no/papers/Mapping%20vulnerability%20CCC2010.pdf]

7.1.10 Wind storms

Effects

In winter, thunderstorms are dangerous particularly for air traffic because during them, the cloud base is rapidly falling down and visibility is suddenly worsening due to heavy snowfall. Combined with the hail, such storms become real danger for airplanes. Other vulnerabilities are destruction of infrastructure and

[34] http://www.stmug.bayern.de/aktuell/presse/detailansicht.htm?tid=14166

buildings, and fires caused by such damage, agricultural loss, damages in the transport (highways, vehicles), etc. Greatest damages are likely to be in North-west Europe and the North Sea (IPCC 2007).

Factors determining exposure

Wind velocity (mean and maximum), together with the kind of the storm (rain, thunder, hail, snow) is determining the destructive force of a storm (ECMWF 2010)[35]. Another essential parameter for the extent of damage is the duration of wind stress. Many losses are only caused by a multitude of "wind attacks" or load changes, which cause material fatigue and finally failure. The direction of the wind is also decisive. Severe changes in direction can influence the extent of loss considerably, if trees with their root system and buildings with their specific load design cannot cope with them. Last but not least, the turbulent nature of the wind leads to its kinetic energy fluctuating very strongly, too. Known as the energy spectrum of the wind, this property has a decisive impact on the extent of damage to trees and resonating structures, particularly bridges, towers, or chimney stacks (Munich Re 2010)[36].

Factors determining sensitivity

When disasters strike small cities and towns, relief efforts and external assistance often lag that which megacities receive. For many rural communities, particularly those within mountainous or rugged terrain or on barrier islands, lack of access following a disaster would greatly hinder both emergency relief efforts and rapid rebuilding (Ibrahim 1988). Physical capacities of people determine their sensitivity to such extreme events as wind storms. Ability to reach safer areas and health services may be limited for elderly people.

When it comes to structures, the sensitivity varies from the characteristics of the structure. For example, high buildings are more sensitive compared to short buildings, since wind speed increases with height. Sharp or protruding roof edges generate wind vortices; therefore they are more sensitive to wind storms than flat roofs. Also sensitivity of buildings very much depends on the material of the exterior walls and facades (Munich Re 2010)[36].

Factors determining adaptive capacity

Forecasting severe weather events and warning the authorities and the public on time is crucial for appropriate mitigating actions to be taken. Early warnings, made a few days ahead of potential events, are of significant benefit, giving additional time to allow contingency plans to be put into place. However, the benefits of this capacity are limited with the society's capacity to utilize it. Income level determines people's capacity to take necessary precautions for protecting from storms as well as their capacity to react in case of an early warning. Low income groups have limited access to transport systems to safe areas and health services; they have limited or no resources to strengthen their houses against wind storms, and are more likely to live in poorly built houses (Brooks et al. 2005).

Education can be considered as an adaptive capacity, since societies with low education levels do not tend to utilize communicational tools to reach the early warning information on time, compared to educated

[35] ECMWF, European Centre for Medium-Range Weather Forecasts, http://www.ecmwf.int.

[36] Munich RE, NATCATSERVICE, Significant Natural catastrophes, http://www.munichre.com/touch/naturalhazards/en/natcatservice/significant_natural_catastrophes.aspx.

societies. Also, empirical literature provides support for positive correlation between warning recipient's knowledge of hazards and his response to the warning (Sharma et al. 2009)

For the natural ecosystems, such as forests, adaptive capacity consists of socio-economic factors determining the capability to implement planned adaptation (Lindner et al. 2010).

Wind storm related hazard maps

The insurance companies have developed hazard maps showing where in the past wind storms have lead to damages. Currently a project in Germany is analyzing these data to derive risk maps based on climatic projections („Auswirkungen des Klimawandels auf die Schadenswirkung in der Versicherungswirtschaft, insbesondere Sturm und Überschwemmung", project partner PIK, until 2011)[37].

7.1.11 Vector borne and other diseases

Effects

The risks of infectious diseases in Europe caused by vectors (such as ticks (e.g. tick-borne encephalitis (TBE), Lyme disease), mosquitoes (e.g. Chikungunya fever, Dengue fever), or sandflies (e.g. visceral leishmaniasis) is likely to increase due to changes in seasonal activity of local vectors and the establishment of tropical and semi-tropical species due to climate change (EEA 2008). Intestinal infectious diseases, such as diarrhoea, that are transmitted through food or water are sensitive to climate and weather components. The quality and safety of seafood is linked to the quality of the water in the coastal zone.

Components determining exposure

Projections for areas of possible establishment of vectors are based on climatic assumptions, climatic constrains on the development of the vectors/and or parasite, population projections and other assumptions (EEA 2008), e.g. for the tiger mosquito winter temperatures, annual rainfall, summer rainfall and summer temperatures seem to be the determining climatic variables (Schaffner et al. 2008). Higher temperatures can contribute to easier replication and wider distribution of vectors, e.g. milder winter temperatures may enable expansion of tick –borne diseases. Water borne diseases are influenced by extreme precipitation events leading to floods or droughts (EEA 2008): Severe flood events can damage or inundate water treatment facilities and contaminate the distribution system, leading to severe water quality problems (EEA 2010b). High temperature and low runoff have a negative effect on microbiological and chemical contamination of waters. Temperature has also a direct affect on the incidence of diarrhoeal and other diseases (EEA 2008).

Components determining sensitivity

Patterns of infectious disease are affected by the movement of people and goods, changes in hosts and pathogens, land use and other environmental components. Personal risk components such as the status o f the immune system play an important role. Water borne diseases will be affected by access to safe water (EEA 2008).

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[37] Pers. Communication Olaf Burghoff, GDV- German Insurance Association, o.burghoff@gdv.de.

Components determining adaptive capacity

The effects of emerging vector will depend on whether the people and health professionals are informed and aware, surveillance systems are in place for early detection and response, vector- and host-control measures as well as preventive measures such as vaccination and treatment are taken. The risks of outbreaks of water-borne diseases decrease where standards of water, sanitation and personal hygiene are high (EEA 2008), e.g. some developed countries have installed multiple barrier water treatment capable of responding to existing and emerging threats (EEA 2010b).

Other drivers than climate change influencing the issue

Climate is only one of many factors influencing vector distribution, such as habitat destruction, land use, pesticide application, and host density[38]. Risks of malaria (and other diseases) are greater in countries where importation of the vectors or pathogens coincides with socio-economic degradation, disintegration of health and social services, uncontrolled cross-border migration and lack of environmental management for vector control (EEA 2008).

Disease related risk maps

For the possible distribution of the Tiger mosquito in Europe, a risk map showing the possible establishment of the tiger mosquito has been developed (EEA 2008). Regional climate related risk maps for projections of ticks distribution will be the output of a running project (2008-20111) at the UBA Germany (Klasen 2009).

7.2 Projects on vulnerability assessments

The identified projects working on vulnerability assessments have been listed in the accompanying Excel file (projects sheet). An overview and short evaluation of the projects is given in section 4.3. The most important data sources for cities and urban areas are listed in Table 15 (see also Excel file, projects sheet).

Table 15. Important data sources for Cities and Urban Areas.

Title	Category and content	Link
Integrated Urban Monitoring in Europe (IUME) of EEA Platform for coordinating and integrating different urban monitoring initiatives.	Information sharing platform	http://iume.ew.eea.europa.eu/
The European Database of Vulnerabilities to Natural Hazards (EVDAB) EVDAB aims to collect and integrate relevant datasets for the identification and the evaluation of key vulnerabilities to weather driven hazards.	Database	http://moland.jrc.ec.europa.eu/evdab/HTML/home.html

[38] http://www.ecdc.europa.eu/en/healthtopics/climate_change/health_effects/pages/ vector_borne_diseases.aspx

Urban Audit Data The Urban Audit provides European urban statistics for 258 cities across 27 European countries. It contains almost 300 statistical indicators presenting information on matters such as demography, society, the economy, the environment, transport and leisure.	Data collection and analysis	http://www.urbanaudit.org
European Climate Assessment and Data set (ECA&D) ECA&D provides access to high resolution climate data obtained from the observational network of the National meteorological and hydrological services in Europe.	Database	http://eca.knmi.nl/
Urban Ecosystem Europe Berrini, M. and Bono, L. (2007): Urban Ecosystem Europe. An integrated assessment on the sustainability of 32 European cities. Ambiente Italia - Research Institute, 81 pages,	Report on 32 European cities	www.dexia.com/docs/2008/2008_news/20080201_urban_ecosystem_UK.pdf
European Green Cities Index Economist Intelligence Unit (2009): European Green City Index. Assessing the environmental impact of Europe's major cities. Siemens report.	Report with 30 cities portraits	http://www.siemens.com/entry/cc/features/urbanization_development/all/en/pdf/report_en.pdf

7.2.1 The European Database of Vulnerabilities to Natural Hazards (EVDAB)

EVDAB aims to collect and integrate relevant datasets for the identification and the evaluation of key vulnerabilities to weather driven hazards.

The EVDAB database is being compiled by the "Floods: Prediction, Mitigation, Impact Assessment" Action of the Land Management and Natural Hazards Unit of the Joint Research Centre Institute for Environment and Sustainability (JRC-IES). The Floods Action aims, amongst others, to assess the impacts of changes in climate and land use and to evaluate adaptation strategies for extreme events. Land management is considered one of the essential keys to identify and implement adaptation strategies to natural hazards while preserving the sustainability of EU regional developments. In this framework the first release of the European Database of Vulnerabilities (EVDAB) aims to support the Clearing House mechanism for adaptation to climate change envisaged in the EC White Paper "Adapting to climate change: Towards a European framework for action" (EC 2009b).

In detail EVDAB focuses on 305 urban areas across the continent with the scope to provide innovative spatial indicators through the collection, integration and analysis of relevant datasets dealing with vulnerabilities to climate changes available at European scale. The targeted urban areas were originally selected in the Eurostat's Urban audit data collection which provided both the reference spatial units of the database and the information on different aspects of the urban life in a cross-section of Europe's cities. In addition to these traditional statistical indicators several datasets generated in the frame of the scientific activities of the JRC and other research communities were ingested into the database providing a more comprehensive description of the study areas. Specifically climate indicators were derived from the regional model provided by the Climate Limited-area Modelling Community (CLM) and from historical observations of meteorological data gathered in the framework of the ECA&D project, flood related issues were analyzed on the basis of the Lisflood model outputs and observed forest fires were investigated relying on the data provided by the European Forest Fire Information System (EFFIS). A general overview of the EVDAB sources and the generated outputs is presented in Figure 21.

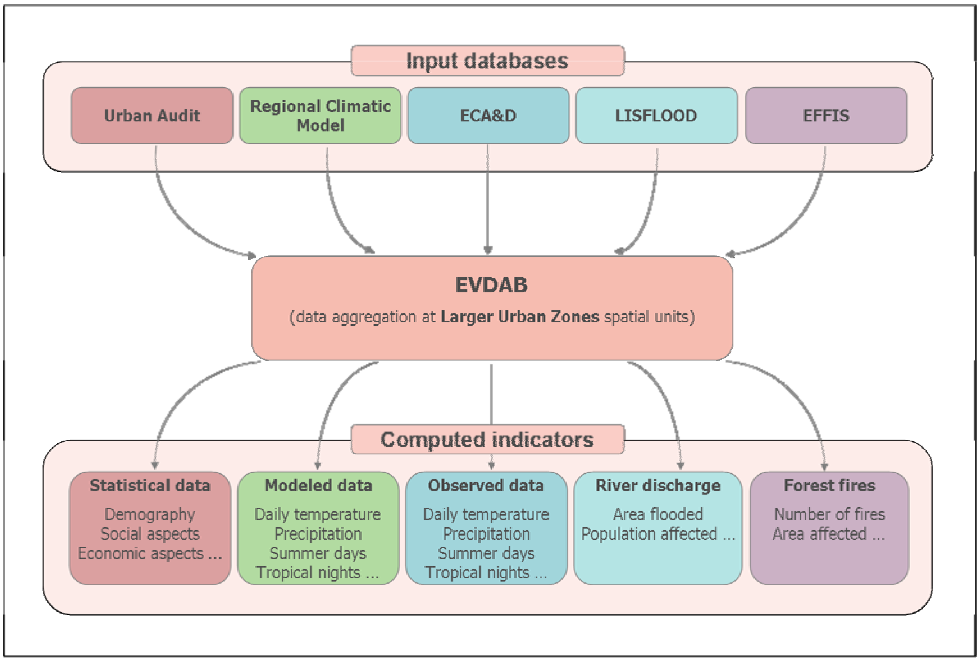

Figure 21. EVDAB structure.

The data generated within those activities (see Table 16) are forecasted to be made available through the European climate change impacts, vulnerability and adaptation clearinghouse. Updates are envisaged in case that improved data sets became accessible. Forest fires, for example, are mapped on a year-by-year basis so that new information is continuously produced. New scenarios or detailed regional climate model outputs could also trigger an update process of the database.

Table 16. Overview of the data available in EVDAB.

`	Indicators	Periods	LUZ coverage	Update	Access
CLM	Projected changes from control to scenario period				
Climate Limited-area Modelling Community	Annual mean of daily mean temperature Annual mean of daily maximum temperature Annual mean of daily minimum temperature No. of Summer days for summer season No. of Tropical nights for summer season No. of Days with HUMIDEX>25 for summer season Mean of total annual precipitation No. of 7-day Heat Wave events for summer season Heating degree days	Control period: 1960-90 Scenario periods: 2010-40 2040-70 2070-00	> 98%	Possible, with the inclusion of the simulations of other climatic models	Planned to be available through the European climate change impacts, vulnerability and adaptation Clearinghouse
ECA&D	Observed data for the reference period				
European Climate Assessment & Dataset	Annual mean of mean daily temperature Annual mean of daily maximum temperature Annual mean of daily minimum temperature No. of days with Tmax>25°C (Summer days) for summer season No. of Days with Tmin>20°C (Tropical nights) for summer season Total annual precipitation Heating degree days	1960-90	>70%	Possible, with the integration of the missing stations data	Planned to be available through the European climate change impacts, vulnerability and adaptation Clearinghouse
Effis	Large Urban Zones with fires larger than 50 ha detected within 10 km radius				
European Forest Fire Information System	Total area burned Total number of fires	2000 to 2007	100%	Possible, Effis is operational and data are gathered for every fire season	Planned to be available through the European climate change impacts, vulnerability and adaptation Clearinghouse

Lisflood hydrological model	Flood risk in European Large Urban Zones under the A2 scenario				
	Land exposure to flood risk Population exposure to flood risk	100-years return flood under the SRES A2 scenario	> 95%	Possible, with the inclusion of simulations for other scenarios or simulations based on different climatic model inputs	Planned to be available through the European climate change impacts, vulnerability and adaptation Clearinghouse

7.2.2 Urban Audit

The Urban Audit is a response to the growing demand for an assessment of the quality of life in European cities, where a significant proportion of European Union citizens live. Organizationally it is a joint effort by the Directorate-General for Regional Policy (DG REGIO) and Eurostat to provide reliable and comparative information on selected urban areas in Member States of the European Union and the candidate countries (Eurostat 2009).

Following a pilot study of 58 cities in 1999, the data collection expanded in 2003/2004 to cover 258 cities. At present the Urban Audit includes 321 cities with a population between 50 000 and 10 million in the EU-27 Member States, 26 Turkish, six Norwegian, 5 Croatian and four Swiss cities.

The cities were selected in cooperation with the national Statistical Offices, and are geographically dispersed to ensure a representative sample (Eurostat 2008). Overall the participating cities in each country should represent about 20% of the population in that country and reflect a good geographic distribution in terms of the periphery/center relation. Coverage should also reflect a sufficient number of medium-sized cities, that is having a population of comprised between 50 000 and 250 000 inhabitants and as the last condition data should be available and comparable. The final selection of participating cities in the Urban Audit represents a compromise between all aspects.

The uniqueness of the Urban Audit data set lies in the extent of its three main dimensions: its wide choice of indicators, its large geographical coverage and its decade-long time series.

Data have been collected on different spatial levels in the Urban Audit (see Figure 22). For it's basic level the Urban Audit uses the administrative definition and delineates the so-called 'core city' according to political and administrative boundaries. Each core city is further divided up into sub-city districts according to population criteria. This second spatial level enables information to be collected on disparities within a city.

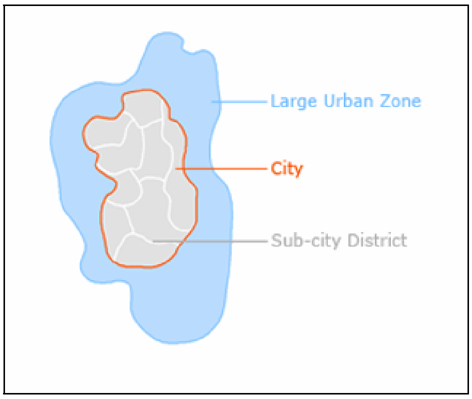

Figure 22. Urban Audit spatial levels.

On the contrary of the administrative approach in defining core cities the functional approach is used to define Larger Urban Zones (LUZ) as the third spatial level of interest. Here the larger urban zone is defined as an approximation of the functional urban zone taking into account the commuting of the work force into the core city to capture information on an extended spatial level since economic activity, labor force or air pollution, etc. evidently cross the administrative boundaries of a city. Therefore the larger urban zone includes the core city and its 'commuter belt'.

More than 300 indicators were defined and calculated, covering most aspects of quality of life, e.g. demography, housing, health, crime, labor market, income disparity, local administration, educational qualifications, environment, climate, travel patterns, information society and cultural infrastructure. The complete list of the domains covered by the Urban Audit dataset is given in Table 17. These indicators are derived from the 336 variables collected by Eurostat. Data availability differs from domain to domain: in the domain of demography, for instance, data are available for more than 90 % of the cities, while in the domain of the environment data are available for less than half of them.

Table 17. Urban Audit domains.

Demography	**Environment**
Population Nationality Household structure	Climate/Geography Air quality and noise Water Waste management Land use
Social aspects	**Travel and transport**
Housing Health Crime	Travel patterns
Economic Aspects	**Information society**
Labor market Economic activity Income disparities and poverty	Users and infrastructure Local e-Government ICT sector
Civic involvement	**Culture and recreation**
Civic involvement Local administration	Culture and recreation Tourism
Training and education	
Education and training provision Educational qualifications	

7.2.3 European Climate Assessment and Data set (ECA&D)

A basic requirement for regional climate assessments is the availability of and the access to high resolution climate data obtained from the observational network (van Engelen et al. 2008). In Europe, this network is managed by a great number of predominantly National Meteorological and Hydrological Services. The common understanding of the necessity for a sustainable operational system for data gathering, archiving, quality control, analysis and dissemination led to implementation of the ECA&D – the "European Climate Assessment and Data set" project.

The core of the ECA data set consists of daily time series provided by the participants throughout Europe and the Mediterranean. Additionally, series from various other projects have been included. Currently the data set includes series of nine climate variables regarding the daily minimum, maximum and mean temperature, precipitation amount, sea level air pressure, snow depth, relative humidity, cloud cover and sunshine duration. Not all stations of the dataset contain series for all these variables and about a half of them comes with restrictions. Nonetheless all the available series are used for ECA&D indices calculations.

ECA&D provides a set of climate change indices that is derived from the daily series. A core set of 26 indices follows the definitions recommended by the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (Klein-Tank et al. 2009). Another 24 indices are specifically for Europe. The station series used for indices calculation in ECA&D are blended series. This means that they are made near-complete by infilling from nearby stations. The indices represent changes in the mean and extremes of the climate, commonly defined in terms of counts of days crossing a seasonal or annual threshold.

7.3 Projects on adaptation options in cities and urban regions

The identified projects working on vulnerability assessments have been listed in the accompanying Excel file (projects sheet). An overview and short evaluation of the projects is given in section 6.1.

7.4 Experts/possible partners of a future project

A list of experts which could support the development of the report in 2011 have been collected (experts sheet), but are only available for internal use. The keywords and the projects in which they are involved indicate their field of expertise.

7.5 Cities who are early adapters

A list of cities which are already active in vulnerability assessment and adaptation planning are given in the excel file based on literature review and information found in the internet. This table needs to be extended by the results of the CoR project.

7.6 Adaptation options for different impacts/vulnerabilities

A list of possible adaptation options for cities and urban areas are given in the Excel file. Only few cites have published information about their adaptation activities in the literature or in the internet. Therefore, it was difficult to fill in this sheet with information on the activities of single cities and their experiences with adaptation options. The given list is purely based on generic literature review. In a follow-up report, the results of the questionnaires and interviews of the CoR project could be used, or it might be possible to encourage the cities via a survey to fill in this table by themselves. However, this will be a time and resource intensive process.

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