Disaster Risk and Climate Impact Research

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1. Introduction

Risk is defined in its broadest sense as "the combination of the probability of an event and its negative consequences" (UN ISDR 2009). Spatial planning comes into play, because it takes decisions for society on whether and how space is used (Greiving 2002).

Concepts for assessing risk from a spatial perspective were first developed by geographers in the 1970s (Hewitt 1971). This was first dominated by a focus on mapping hazards ('hazards of place') and risks. However, as Cutter (1996) noted, further methodological elaborations on this subject were only rarely attempted until the mid-1990s. It is due to authors like Burby (1998) or Godschalk et al. (1999) that the important role of land-use planning, and how it plays out in the whole disaster management cycle, was highlighted.

There is also an ongoing discussion on transformative resilience focusing on a system's capacity to adapt or transform in the face of emerging multi-risks to support sustainability (Pelling 2011; Biggs et al. 2015). For its application in the practice of disaster management and urban sustainability, building resilience for reducing vulnerability needs flexibility, learning and change (Adger et al. 2005) as well as a participatory and inclusive approach allowing vulnerable individuals and groups to play an active role in determining how best to avoid hazards and build capacity and, ultimately, just cities (Sarabia et al. 2020). These theoretical discussions on sustainability and resilience clearly underline the importance of community-based strategies which are tailor-made to specific legal and cultural contexts.

Spatial planning is asked to coordinate different demands on space with one another and conflicts arising at the respective planning levels are to be balanced out. This calls for a multi-risk perspective which considers all spatially relevant hazards, but also the specific vulnerability of various land-use classes, infrastructures and social groups (Greiving 2011).

Decision-making on tolerating or altering risks requires a sound evidence basis in terms of a multi-risk assessment which determines the total risk from several hazards either occurring at the same time or shortly following each other. They may be dependent from one another or caused by the same triggering event or hazard; or merely

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threatening the same elements at risk (vulnerable/exposed elements) without chronological coincidence (EC 2010). In contrast to the well-established assessment of single hazards and risks, this kind of assessment looks at the interdependencies of the occurring hazards and requires a consideration of cascading effects, even outside the exposed area. Coinciding hazards can result in cumulative and cascading effects, meaning that one hazard can follow up with subsequent hazards with bigger impacts and, in total, accumulate negative effects. However, multi-risk perspectives are not systematically addressed among disaster risk management approaches and single-hazard maps are still the decision support tool most often used (Poljanšek et al. 2017). Challenges of assessing multi-risks occur because of the interdependencies of sectors and related communication channels, and require multi-risk governance (Renn 2008; Scolobig et al. 2014).

However, the impacts of extreme events are not solely determined by a given place-based hazard and vulnerability profile, but considerably influenced by cascading effects caused by the service disruptions of critical infrastructures (CI), which may even take place outside the exposed areas (Pescaroli/Alexander 2016). For example, the current Covid-19 pandemic is costing between 8.1 and 15.8 trillion USD globally, primarily because of disrupted global supply chains (World Economic Forum 2020).

The European Union defines critical infrastructure as "assets or systems, essential for the maintenance of vital social functions, health, safety, security and economic or social wellbeing of people" (see Art. 2, Council Directive 2008/114/EC). This directive determined the following criteria for criticality (see Art. 3 § 2), but does not provide a methodology for assessing criticality holistically:

- Causalities criterion: assessed in terms of the potential number of fatalities or injuries;
- Economic effects criterion: assessed in terms of the significance of economic loss and/or degradation of products or services; including potential environmental effects;
- Public effects criterion: assessed in terms of the impact on public confidence, physical suffering and disruption of daily life; including the loss of essential services.

However, negative consequences caused by hazards of any kind are typically assessed through an examination of vulnerability. Established disaster risk concepts cannot address the systemic criticality of CI systems and subsystems (Hellström 2007). Moreover, risk and vulnerability are place-based concepts, but the CI systems are of functional character. Consequently, the systemic focus of criticality runs counter to the areal-oriented view of spatial planning, which is primarily asked to place key infrastructure elements outside exposed areas (Greiving et al. 2016). In addition to a multi-risk assessment and its output, a parallel string, the assessment of criticality, is needed.

Multi-risk assessment and management is an issue in the Sendai Framework for Disaster Risk Reduction, which propagates disaster risk reduction practices "to be multi-hazard and multi-sectoral, inclusive and accessible in order to be efficient and effective" (UNISDR 2015:10). The New Urban Agenda (UN 2017) vows to "commit ourselves to strengthening the resilience of cities and human settlements, including through the development of quality infrastructure and spatial planning […], especially

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in risk-prone areas of formal and informal settlements." Sustainable Development Goal 11 points at "a significant reducing of the number of deaths and the number of people affected and substantial decrease of the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations."

In principle, there are a couple of explicit relationships between several targets of the SDGs and the Sendai Framework, namely SDGs 1, 11 and 13: eradication of poverty, resilient and sustainable cities, and action to climate change, as shown by fig. 1.

Fig. 1: Sendai Framework and the 2030 Agenda (UN-ISDR 2019)

For these communalities, a joint monitoring scheme has been adopted by the UN (UNISDR 2019).

The climate has always been changing as a result of changes in various factors such as solar activity, the earth's orbit around the sun, the atmospheric composition and large volcanic activities (EEA 2017). The extent and impact of human influence on today's and the future's climate system has become evident as recent anthropogenic emissions of greenhouse gases have reached the highest level in human history. Consequently, recent climate changes have already had widespread impacts on human and natural systems and will have even more severe impacts in the future (IPCC 2014).

In contrast to climate protection, which requires global action, climate adaptation is primarily a local to regional task due to the specific, territorially diverse impacts of climate change on a small scale (EEA 2013). Cities are not only particularly affected by climate change, but urban development also plays a decisive role, as it is responsible for the control of many fields of action affected by climate change, such as settlement, open space and transport development, but also human health (Deutscher Städtetag 2012). Spatial planning is of central importance for the reduction of vulnerability as well as the targeted development of climate protection and adaptation capacities against the im-

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pacts of climate change (Stern 2006; IPCC 2014). The German Adaptation Strategy (DAS, Federal Government 2008: 42) also emphasizes: "Spatial, regional and urban land-use planning are at the beginning of the risk prevention chain, as they develop spatial precautionary concepts, the planning documents are of long duration and legally binding, and there are sometimes long lead times before the plan contents can be implemented in practice". In this context, climate adaptation is to be seen as an integrated component of urban development that also keeps an eye on interactions (synergies and conflicts) with other challenges such as climate protection or demographic change (Greiving/Fleischhauer 2012).

There is a need for better informed decision-making in addressing these impacts amidst a changing and uncertain environment (EC 2013. The extent and territorial patterns of these impacts cannot be precisely predicted due to uncertainty with regard to further greenhouse gas emissions, which depend on demographic, socio-economic and technological development. Moreover, there is always an enormous bandwidth of potential future local socio-economic conditions. Addressing the deep uncertainty of the future status of both climate and society calls for flexible, resilient adaptation strategies (Walker/Haasnoot/Kwakkel 2013). But also the implementation of global, national and local mitigation policies in the future is uncertain (EEA 2012). In general, "uncertainties about future climate change are smaller for changes in temperature than for precipitation and other climate variables, for changes at global and continental scales than at regional scale, and for changes in mean climate than for extreme events" (EEA 2017, 54).

There are connections between climate change on the one hand and hydro-meteorological extreme events on the other hand. The combined impacts of projected climate change and socio-economic developments (e.g., in floodplains) that trigger vulnerability and exposure lead to higher damage costs (EEA 2017). Disaster risk management can therefore contribute to climate change adaptation. Thus, both fields of action need to be coordinated (Field et al. 2012; Costa/Kropp 2012; EC 2021), see also fig. 2:

Nonetheless, the scope of adaptation to climate change goes beyond dealing with extreme events and addresses also creeping changes in temperature and precipitation and related impacts on the society and the environment. Moreover, several hazards which are hardly or not at all influenced by climate change such as volcanic eruptions or earthquakes are to be considered by disaster risk management. Consequently, the related assessment frameworks fundamentally differ. (Probabilistic) disaster risk assessments are based on statistics from past events, whereas the assessment of potential future impacts of climate change requires a prospective, scenario-based approach (Greiving 2019). Consequently, this paper addresses disaster risk and climate impact assessment methodologies separately.

2. Assessment Methodologies

In planning and decision-making processes, evaluation and decision-making phases are often interwoven. Nevertheless, the level at which facts are determined for the subsequent decision must be separated from the process level at which these facts are eval-

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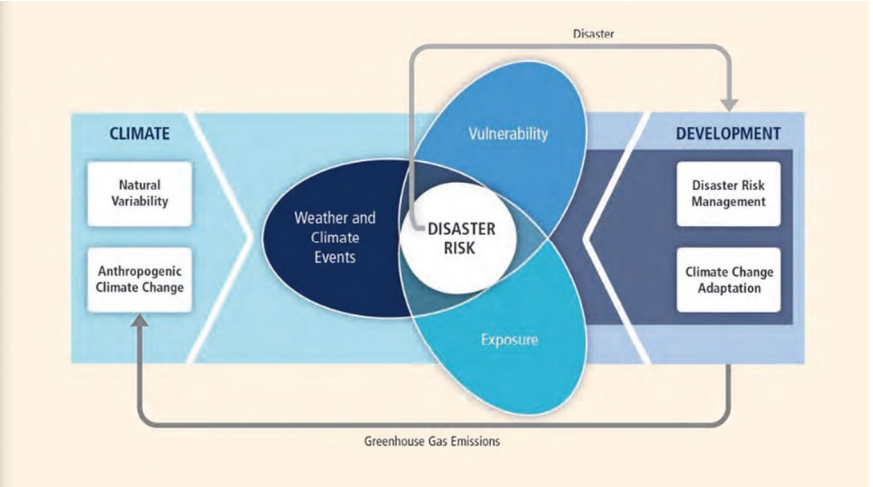
Fig. 2: Climate change and disaster risk. Source: Field et al. (2012)



uated and decisions are made by politically legitimized representatives. Defined goals serve here as a normative basis for the evaluation of the determined facts.

Assessment and evaluation methods generally serve to structure the complex evaluation process in terms of both form and content (Scholles 2005). Accordingly, they consist of a factual model, a target system as well as allocation and aggregation rules. They can also reduce the complexity of the factual level and focus the political decision-making problem on those questions that are to be assigned to the (political) value level and clarified in the target system. There is no one-size-fits-all evaluation method, but only more or less appropriate procedures, whereby the appropriateness can only be judged in the individual case and the given framework conditions. It is undisputed that the chosen methodological approach must be consistent in itself (Faßbender 2012).

Risk can be presented in a number of different ways, depending on the objectives of the risk assessment. It can be expressed in absolute or relative terms. Absolute population risk can be shown as individual risk or as societal risk (the relation between the annual probability and the number of fatalities). Absolute economic risk can be presented in terms of average annual losses or maximum probable loss, each with a relation between frequency and expected monetary losses.

In any case, a differentiation is needed between direct risk (which is the risk directly resulting from the impact of the hazard) and indirect risk (which may occur later as a consequence of the direct impact due to cascading effects). Examples of indirect losses are loss of revenues and economic production, disruption of transportation networks leading to longer travel time etc. Significant components of losses are intangibles (difficult or impossible to quantify), for example the societal or psychological impacts of disasters.

Risk assessment as such is a process to determine the probability of losses by analysing potential hazards and evaluating existing conditions of vulnerability that

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could pose a threat or harm to property, people, livelihoods and the environment on which they depend. DIN ISO 31000 (2018) defines risk assessment as a process made up of three steps:

- Risk identification is the process that is used to find, recognize, and describe the risks that could affect the achievement of objectives.
- Risk analysis is the process that is used to understand the nature, sources, and causes of the risks that have been identified and to estimate the level of risk. It is also used to study impacts and consequences and to examine the controls that currently exist.
- Risk evaluation is the process that is used to compare risk analysis results with risk criteria in order to determine whether or not a specified level of risk is acceptable or tolerable.

The process can be carried out at a number of scales and for different purposes.

2.1 Probabilistic Approaches

Probabilistic approaches are based on a quantification of the risk caused by a certain hazard. In this quantification, the probability of occurrence of one or all conceivable damaging events is first determined. Furthermore, the effects and the extent of such events are quantified. The risk is the product of the probability of occurrence and the extent of the impact. If the risk is determined via the integral of all conceivable or observed frequency-magnitude relationships, damage functions can be derived in this way, which can also be expressed as annualized quantities or "annualized average losses".

These damage functions are then suitable for a cost-benefit analysis of protective measures, whereby the protection in the sense of a reduction of the damage expectation values is considered on the benefit side and the efforts to plan, construct and operate the protective structure matter on the cost side.

Another characteristic of the probabilistic approach is that the risk analysis is to be carried out repeatedly. This is the case, for example, if changes in the environment (for example, settlement density) lead to changes in vulnerability, even if the probability of occurrence has not changed.

In a probabilistic risk analysis, the weight of the concern results from the combination of the probability of occurrence and the consequence of certain events. The scope for consideration then consists of whether a (probabilistically) determinable risk should be accepted because other concerns are given priority, or whether this is not to be accepted. In the latter case, the planning justification must transparently explain in detail which technical data and forecasts were used and for what reasons. Deterministic approaches (see section 2.2) do not know such a scope of consideration.

The planning authority must not be content with a schematic and abstract assessment. Rather, the assessments and forecasts must be plausible on the basis of the empirical material required in each case. For this purpose, a methodological approach of the relevant risk analysis must be explained and adopted by the planning authority. The determination of the factual basis and the consistency of the methodological approach

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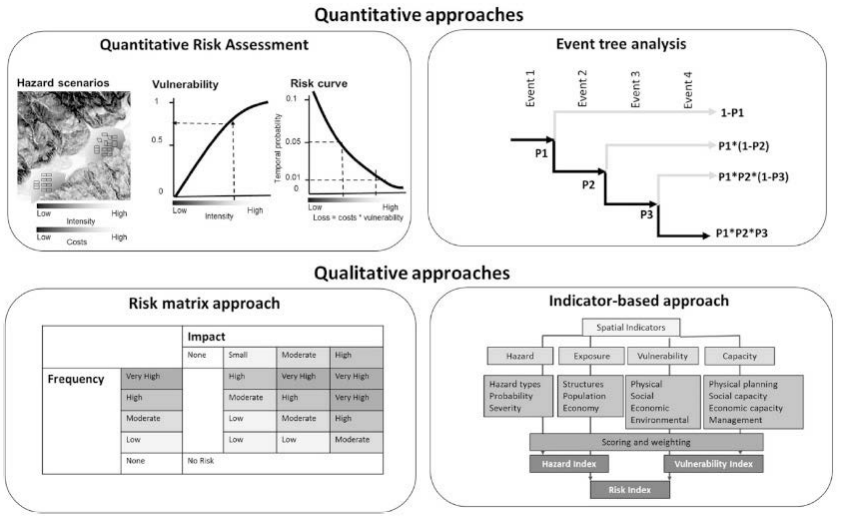
is of great importance for the legality of the planning consideration, which is based on this methodology.

Within probabilistic approaches, a distinction can be made between quantitative and qualitative risk analyses (see fig. 3):

- Quantitative risk assessment (QRA), Event-tree analysis (ETA), Risk matrix approach (RMA) and Indicator-based approach (IBA).
- Quantitative approaches can be used for deriving CBA as basis for the judgement of mitigation measures, but disregard intangible elements of risk.
- Qualitative approaches are highly scale-dependent and express only relative ratios between different areas of investigation.

Fig. 3: Risk assessment approaches. Source: van Westen/Greiving (2017)



Quantitative approaches are established as a basis for the economic efficiency of protective measures and are used to calculate premiums in the insurance industry, but they cannot capture intangible factors. While quantitative risk assessments are established above all for natural hazards, for which corresponding time series from past events are available, (rare) technical incidents are usually investigated using so-called event-tree analyses, since there is a lack of comparable cases. In this case, all conceivable accident sequences are examined and the risk is determined by summing up all individual effect chains.

Qualitative approaches are scale-dependent and only express relative ratios between the units of a study area. However, min-max normalizations can be used to transfer indicators to a harmonized scale and thus also capture intangible factors.

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The risk matrix approach is used, for example, by the BBK (German Federal Office of Civil Protection and Disaster Assistance) for risk analyses in population protection (BBK 2010) and sometimes adapted for spatial planning purposes (Greiving et al. 2016).

Indicator-based approaches are mainly applied at the global or European level (Schmidt-Thomé/Greiving 2013). Due to the size of the study areas, proxy indicators are used in an attempt to determine a given risk measure or to make study units such as nation-states or counties comparable with each other, whereby the selection of indicators and weighting factors for each indicator considerably determines the overall result.

2.2 Deterministic Approaches

In deterministic approaches, decisions are not based on an explicitly calculated risk, but on a set of design cases. Coastal flood defence structures in Germany are designed for a reference case which is derived from the highest observed sea level in history (for the North Sea, this is the storm surge that hit Germany in 1976, for the Baltic Sea the 1872 event), but not linked to a certain return period. In fluvial flood protection, this form of rule-based action is found in Art. 78 § 1 No. 1 Federal Water Act (WHG): "In designated floodplains, the designation of new building areas in urban land-use plans or in other statutes according to the Building Code is prohibited." This rule applies regardless of the level of the existing flood risk within the floodplain (new buildings are prohibited) or (in the case of extreme floods or dike breaches) outside of floodplains where all developments – even of specifically dangerous facilities or critical infrastructures are allowed. Defined safety standards for locations where dangerous substances are stored or processes are based on a deterministically chosen major accident design case which lacks a certain return period (see Art. 4 directive 2012/18/EU on the control of major-accident hazards involving dangerous substances in accordance with Art. 50 Federal Immission Protection Act [BImSchG]).

Deterministic approaches are common for conditional-programmed law-making via rule-bound decisions. Conditional programming can be defined as the rule-based assignment of facts to normative factual prerequisites from which a certain legal consequence inevitably results (for example, the entitlement to an operating permit if safety standards are met). A rule is a prohibition or requirement that comes into effect if a condition contained in the rule is met. If two rules conflict, exceptions must be made or a rule must be declared invalid. Rules are to be understood as the result of a compromise decision between conflicting principles that has already been made by the norm maker (e.g., federal legislator) and is binding for the norm user (e.g., a lower water authority). If rules exist for a certain issue, they must be followed. In weighting-up processes, these rules can be found as so-called planning principles or target binding clauses (e.g., the obligation to adapt to the objectives of regional planning according to Art 1 § 4 Federal Building Code (BauGB). In this context, these rules represent mandatory legal regulations that control public planning, i.e. also urban land-use planning, by ordering their strict observance.

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2.3 Scenario-Based Approaches

Climate change itself, but in particular its regional and local impacts are characterised by deep uncertainties (van Asselt 2005; Walker et al. 2013; Reckien et al. 2014). Data from past events which inform probabilistic approaches are not representative anymore in view of the changing framework conditions.

The uncertainties about future climate change impacts require a scenario-based, so-called "parallel modelling approach".[1] This means that demographic and socio-economic changes are projected in parallel to the changes of the climatic system in order to assess the future impacts of climate change on a future society. This is not only relevant on the global level as a basis for emission scenarios, but also on the regional and local levels in order derive tailor-made adaptation strategies (van Ruijven et al. 2014; Greiving et al. 2018). In this context, the assessment should be based on a scenario combination of climatic scenarios derived from an ensemble of climatic models and socio-economic scenarios in order to reflect the bandwidth of potential future conditions (see fig. 4).

The recent amendment of the Environmental Impact Assessment Directive (2014/52/EU) underlines the need for a parallel modelling approach by stating: "Climate change will continue to cause damage to the environment and compromise economic development. In this regard, it is appropriate to assess the impact of projects on climate (for example greenhouse gas emissions) and their vulnerability to climate change" (EC 2014). Consequently, a so called "evolving baseline trend" (of both climate and society) has to be taken into account when assessing the effects of a plan or project on the environment (EEA 2013). A similar reference is still missing in the Strategic Environmental Directive (2001/42/EC), although the DG Environment argued for an inclusion of climate change (EC DG Environment 2013).

The change of the sensitivity (i.e. demographic change, economic change and change in land-use patterns) may determine – at least for rapidly growing or shrinking urban environments – the extent of climate- and weather-related impacts in the near future more significantly than the changing climate (temperature and precipitation mainly) itself (Greiving et al. 2018). Due to this fact, for each time slice (present and future), a potential impact needs to be determined using either only recent monitoring data or only projections (for both, changes in the climate and the socio-economic changes are taken into account). In doing so, the dynamics of climate change impacts can be determined.

Adaptive capacity is left out of the climate impact assessment framework. That is particularly relevant because adaptive capacity by definition only relates to the future,

1 The "parallel modelling approach" was introduced in IPCC AR5 (IPCC 2014) with the parallel approach of the "Representative Concentration Pathways". As succinctly described by van Vuuren et al. (2011) "Socio-economic and emission scenarios are used in parallel to provide plausible descriptions of how the future may evolve with respect to a range of variables including socio-economic change, technological change, energy and land use, and emissions of greenhouse gases and air pollutants. They are used as input for climate model runs" (van Vuuren et al. 2011, 6). This (global) parallel modelling approach was further elaborated with stress placed on local and regional levels (and land use at these levels) as a basis for assessment of possible local and regional climate impacts by van Ruijven et al. (2014) and Greiving et al. (2015).

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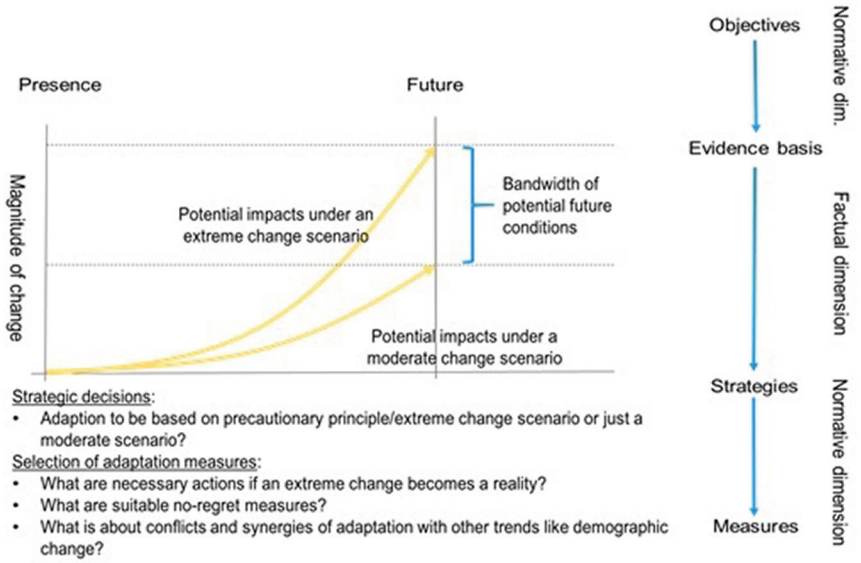
Fig. 4: The parallel modelling approach. Source: Greiving et al. (2018)



i.e. to the possibility of implementing additional adaptation measures. The climate impact assessment approach presented here aims at creating a sound evidence basis for decisions on adaptation to climate change. Taking potential adaptation measures into account already during the assessment phase would definitely weaken the awareness and willingness of decision-makers to give priority to adaption against other conflicting social or economic interests.

A central question within the parallel modelling approach is how to address the uncertainty of future developments. In the approach presented here, the inherent uncertainty of climatic models is taken into account by using an ensemble which considers several global and regional models, as well as socio-economic emission scenarios. Two ensemble members are used in parallel for each climatic stimulus (e.g., the 15^{th} and 85^{th} percentiles of all ensemble members).

The uncertainty related to future socio-economic conditions should be taken into consideration by using different sensitivity scenarios (represented by the key variables changes in demography and land-use). This means, in case of population data, to pick different population scenarios and build an ensemble of these and subsequently build percentiles (e.g., the 15^{th} and 85^{th}). However, the specific availability of different sensitivity scenarios has to be checked case-by-case. This method seems to be appropriate in case of a high uncertainty. In contrast, there might be cases where the specific development of the future sensitivity can be quite certain. If so, it may be applicable to include only one (realistic) sensitivity scenario for representing the future (e.g., if the sensitivity remains stable or the development is well-known). However, a key component of this approach is to base decisions on scenario combinations of climate change and changes

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in the sensitivity instead of just a change of the climatic system. That is also why fig. 4 shows a bandwidth of potential future conditions that is fed by both trends.

Nevertheless, normative questions remain: On which scenario combination should an adaptation strategy and subsequently the adaptation measures be based? A combination of rapid land-use change under extreme climate change or a more moderate one? The role of science in this context is problematic because science cannot give a proof of future climate impacts in view of given uncertainty. Science in this context is inconclusive (van Asselt 2005). Hereby, justification of actions and consensus about thresholds for acceptable risks and response actions becomes more important (Fleischhauer et al. 2012; Walker/Tweed/Whittle 2014).

3. Applications in Spatial Planning

3.1 Probabilistic Flood Risk Assessment

Pluvial flooding as local phenomenon is not classified as flooding by the Federal Water Act (WHG). This understanding is in line with Art. 2 § 1 Floods Directive 2007/60/EC ("may exclude floods from sewerage systems"). Instead, the WHG addresses pluvial flooding in section 2, which is on sewage water treatment (Art. 54 No. 2 WHG). Consequently, the responsibilities for pluvial flood risk assessment and management are up to the municipalities as responsible public bodies for sewage water treatment (see Art. 56 WHG).

Priority zone flood protectionState-of-the-art probabilistic pluvial flood hazard assessments are two-dimensional (2D) surface run-off calculations with hydrodynamic models (LAWA 2018, Othmer/Becker/Schulte/Greiving 2020). In most cases, such kind of assessments are provided by expert statements of consultancy companies on behalf of municipalities. The German Met Office (*Deutscher Wetterdienst, DWD*) offers statistical data on extreme rainfall events of different durations and return periods on a grid cell basis (8 x 8 km) for the entire country. This information is based on the reference period 1951 to 2010 and does not consider potential impacts of future climate change on precipitation patterns (DWD 2020). For this purpose, the German Association for Water, Wastewater and Waste (DWA) developed area-specific "Enhancement Factors" which serve as multiplier of the statistical data on past rainfall events (Schmitt et al. 2018).

The following fig. 5 shows an exemplary hazard map (scale 1/2000) for the City of Olfen, based on a rainfall event of 90 l/m² and a duration of 60 min (return period 100 years).

The hazard map is typically overlaid with information on land-use and infrastructures in order to determine a pluvial flood risk. Clearly visible are the water streams and inundation depth (partly more than 1 m in built-up areas). In some cases, the water streams follow former creeks which were covered by settlements or infrastructures. The numbers 1-3 indicate exposed infrastructures at risk (1= town hall, 2 = elementary school, 3= retirement home). Municipalities are asked to consider pluvial flood risks within land-use planning and sewage water treatment.

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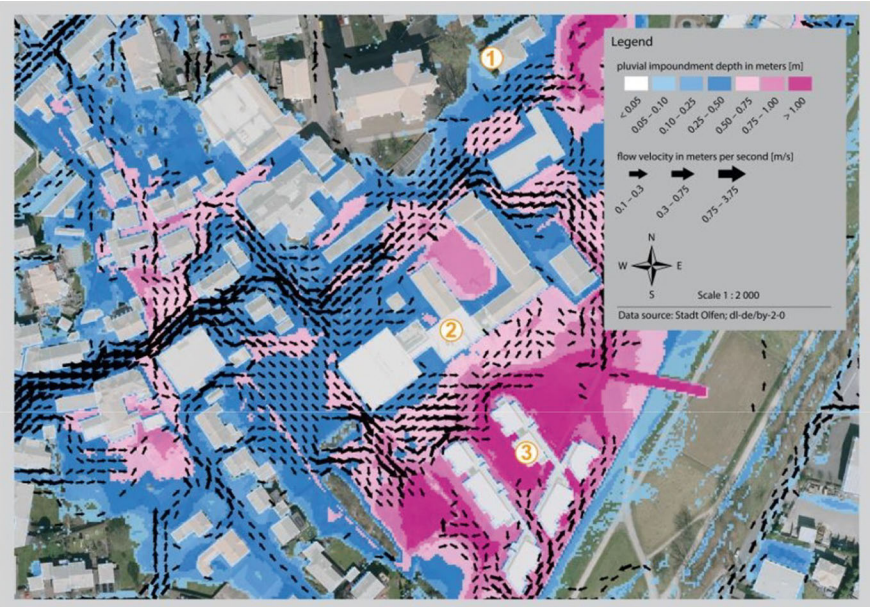
Fig. 5: Pluvial flood hazard map (Source: Othmer et al. 2020, 11)



3.2 Scenario-Based Climate Impact Assessment

The project InKlaH (Integrated adaptation concept for the City of Hagen) aimed at an integrated adaptation strategy to climate change and demographic change for the City of Hagen. It is intended to mainstream adaptation by coordinating actions like mitigation of urban heat and flood risk management strategies with land-use and landscape planning of the City of Hagen. This strategy was informed by an impact assessment that followed the parallel modelling approach.

For the analysis of urban heat, a holistic approach was applied in order to estimate the impact on human health from both, climatic and demographic change. For projecting the influence of climate change on the urban climate, the change in the number of heat days (more than 30 °C) and tropical nights (more than 20 °C) was projected. In this context, known potential changes in the settlements structure (depicted from political debates) were taken into account for calculating the future urban climate by means of the urban climate model ENVIMET (Bruse and Fleer 1998). Basis of the sensitivity analysis was the number and the change in the number of people in the age groups younger than 6 and older than 65 years between 2015 and 2050. Additionally, the working population was considered since especially the day time heat island effect will most likely increase in the future and may lead, e.g., to a lower productivity (Greiving et al. 2016).

Fig. 6 shows the change of the impact of urban heat on human health. It is based on a composite index that merges heat days/tropical nights (equally weighted) with the number and density of the population per city quarter (age groups were differently

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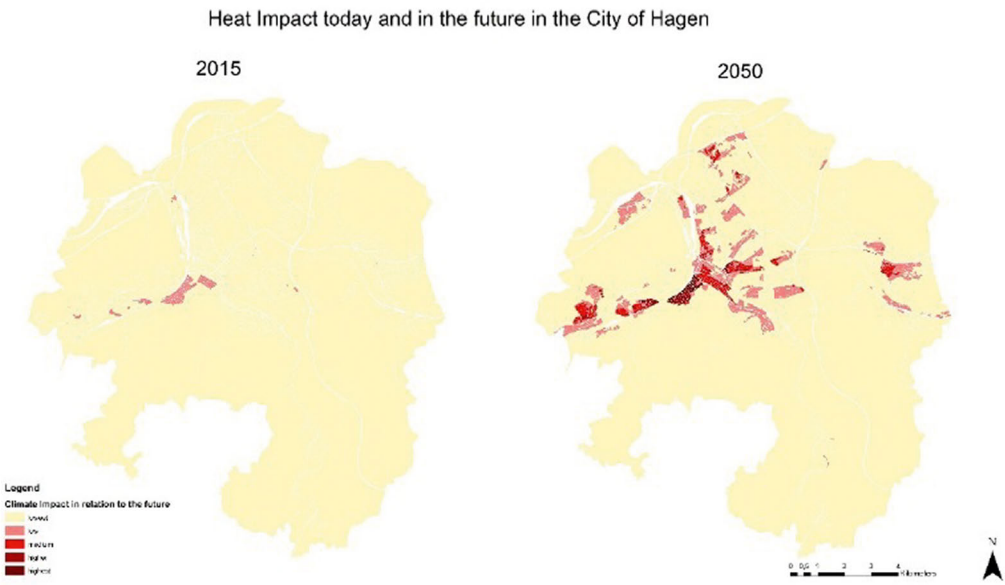
weighted in accordance with their sensitivity to heat stress). The heat-related impact was calculated for the present and the future. The values were normalised (0–1) over both time slices in order to visualise the change of the impact over time. It becomes clear that tomorrow's impact on human health in suburban residential areas will be more serious than it is today in the densely populated city centre.

Fig. 6: Temporal change of the heat island effect in the City of Hagen (Source: Greiving et al. 2018)



4. Perspectives and Access Points

Art. 3 § 2 Directive 2014/52/EU on the assessment of the effects of certain public and private projects on the environment points at the importance of "expected effects deriving from the vulnerability of the project to risks of major accidents and/or disasters that are relevant to the project concerned." The directive was implemented into national German planning law by Art. 1 § 6 No. 7 j) Federal Building Code (BauGB) and annex I § 2 ee) BauGB. The same applies for "the impact of the proposed projects on the climate (for example, the nature and extent of greenhouse gas emissions) and the vulnerability of the proposed projects to the impacts of climate change." [Annex I § 2 gg] BauGB). These legal regulations underline the need for risk and climate impact assessments as part of environmental assessments. Consequently, all planning authorities are obliged to consider disaster risks and impacts of climate change when setting up spatial plans or programs.

However, Art 5 § 2 Strategic Environmental Assessment Directive (2001/42/EC) states:

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> The environmental report […] shall include the information that may reasonably be required taking into account […] the contents and level of detail in the plan or programme, its stage in the decision-making process and the extent to which certain matters are more appropriately assessed at different levels in that process in order to avoid duplication of the assessment.

Different spatial scales require adjusted methods for both, disaster risk and climate impact assessment. On the national and regional levels, risk index or indicator-based approaches are suitable for the identification of hot-spots. For large-scaled climate impact assessments, grid-cell-based land-use models informed by demographic projections are the appropriate way to assess a changing sensitivity due to a lack of detailed knowledge on potential local land-use changes.

For local risk assessment, a probabilistic approach which is driven by damage models is recommendable in order to determine a given risk. By doing so, appropriate risk reduction measures can be economically judged and land-use plans adequately adjusted.

For local climate impact assessments, modelling is equally important, but must consider fine-grained demographic data including information on age groups, social milieus, data which allows a more precise assessment of the changing sensitivity. Moreover, reliable scenarios for local land-use change can be created based on reasonable alternatives of further settlement expansion or urban renewal. These scenarios enable an iterative process between urban climatic modellers and urban developers. In doing so, planning alternatives can be derived that are optimized to the potential future status of the climate. That is exactly what Directive 2001/42/EC requires when asking for these "reasonable alternatives" (see Art. 5 § 1) but what has rarely been done in planning practice.

Generally speaking, the quality of assessment depends – apart from the chosen methods – on the quality of the input data. An enormous challenge in this regard is the lack of available and reliable demographic data – and subsequently land-use data – for the remote future. There is definitely a need for future research in this respect. Another limiting factor is the deep uncertainty concerning the future potential change of the local patterns of extreme events such as urban flooding. Here, the available data from regional climatic models is not sufficient as it offers for instance just the 98th percentile data for daily rainfall, which does not represent real extreme events, but needs to be replaced by deterministically chosen enhancement factors (Schmitt et al. 2018).

It was shown that spatial planning is asked to consider both disaster risk and climate change for decisions on urban and regional development. The necessary evidence basis requires a set of methodological tools. Here, GIS-based modelling of today's and tomorrow's potential characteristics of hazard and vulnerability patterns is a key component. However, qualitative methods such as needs assessments, interviews and participatory approaches are of equal relevance. Normative decisions are needed for determining the framework conditions for scenarios and selecting reasonable alternatives, but also for decisions about tolerating or altering risks. Thus, risk management and adaptation to climate change need to be organised in a collaborative way which takes the knowledge, but also the concerns of the addressees into full account – from the early beginning of

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the problem framing and the assessment phase to the selection of risk reduction and adaptation measures.

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