2.3 The most recent view of vulnerability

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2.3.1 The importance of vulnerability for disaster risk assessment

2.3.1.1 Vulnerability: a key component to determine risks

Disaster risk is determined by the combination of physical hazards and the vulnerabilities of exposed elements. Vulnerability relates to the susceptibility of assets such as objects, systems (or part thereof) and populations exposed to disturbances, stressors or shocks as well as to the lack of capacity to cope with and to adapt to these adverse conditions. Vulnerability is dynamic, multifaceted and composed of various dimensions, all of which have to be considered within a holistic vulnerability assessment.

Vulnerability plays a fundamental role for understanding, assessing and reducing risks. When a hazardous event occurs — be it of natural, technological or man-made origin — the vulnerability of exposed people, objects (e.g. critical infrastructure, etc.) and systems (e.g. socioecological systems) at different scales is key to determine the severity of the impact. Though this fact has been widely accepted, the definition of vulnerability and the components it comprises varies between different authors and disciplines.

The United Nations Office for Disaster Risk Reduction (UNISDR Terminology, 2017) defines vulnerability as 'the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. This definition reflects the last decades' shift in the understanding of vulnerability from a focused concept (for example limited to physical resistance of engineering structures) to a more holistic and systemic approach. At the same time, it does not provide reference to the political/institutional situation and does not account for power relations or the heterogeneity within communities, which are aspects considered as important and included in the definitions proposed by other authors (Cardona et al. 2012, Alexander 2013, Birkmann et al. 2013, Wisner 2016)

Vulnerability represents a fundamental component of risk. A proper understanding of vulnerability comprising its dimensions as well as its root causes is important for effective risk assessment and risk reduction.

The significance of vulnerability for assessing risk is emphasised by the fact that the consequences of a hazardous event largely depend on human factors. That is, the hazardous event itself may be predominantly an external phenomena out of the control of those affected; any devastating impact caused by this event, however, is mainly influenced by inherent societal conditions and processes.

The L'Aquila earthquake in April 2009 in Italy is an example of a medium-power seismic event that had a disproportionately large human impact. It caused 308 fatalities, most of which were the young and elderly, as well as women. The death toll is partially linked to the high vulnerability of building stock in the mountains of Abruzzo. It is in part explained by the risk perception among female victims, who tend to be more fatalistic than men and who perceived their homes as a refuge, instead of leaving it (Alexander, 2010; Alexander and Magni, 2013).

The degree of vulnerability within a society or a population group is usually not homogenously distributed; social class, ethnic origin, age and gender may determine a lower or higher probability of being affected. Evidence of this fact has been shown by the impact of Hurricane Katrina, which caused a disproportionately high number of victims amongst the poor black and elderly population in New Orleans in 2005 (Cutter et al., 2006).

Addressing vulnerability — together with exposure — represents the gateway for risk reduction measures. Consequently, the importance of vulnerability for DRM is underlined by the Sendai framework for disaster risk reduction, claiming that understanding disaster risk (Priority 1) and developing related policies and practices need to consider the various dimensions of vulnerability (UNISDR 2015a).

2.3.1.2

BOX 2.1

Resilience and capacities

Besides the notion of 'vulnerability' there are other terms and concepts addressing the possibility of harm to a system, people or specific objects by certain events and processes. Vulnerability – understood as a holistic and systemic concept – is closely related to and partly overlaps, for example, with the concepts of resilience and of coping and adaptive capacity.

'Resilience' is a term that has been widely used over the last years to describe characteristics related to the ability to absorb stresses, to respond to changes and to recover from shocks. Some authors see resilience as the positive flipside of vulnerability. A broader understanding of resilience incorporates the ability and willingness to learn, to reorganise and to undertake critical self-reflection (Alexander 2013, Kelman et al. 2016). Climate resilience has emerged into a new doctrine under the umbrella of which communities define the activities to combat the impending implications of climate change.

There are numerous related activities within Europe, for example the RESIN project is investigating climate resilience in European cities, the European Commission's FP7 project emBRACE has focused on community resilience and developed a set of key indicators for assessing it, and the Commission's Horizon 2020 project 'resilens' is scrutinising the resilience of European critical infrastructure.

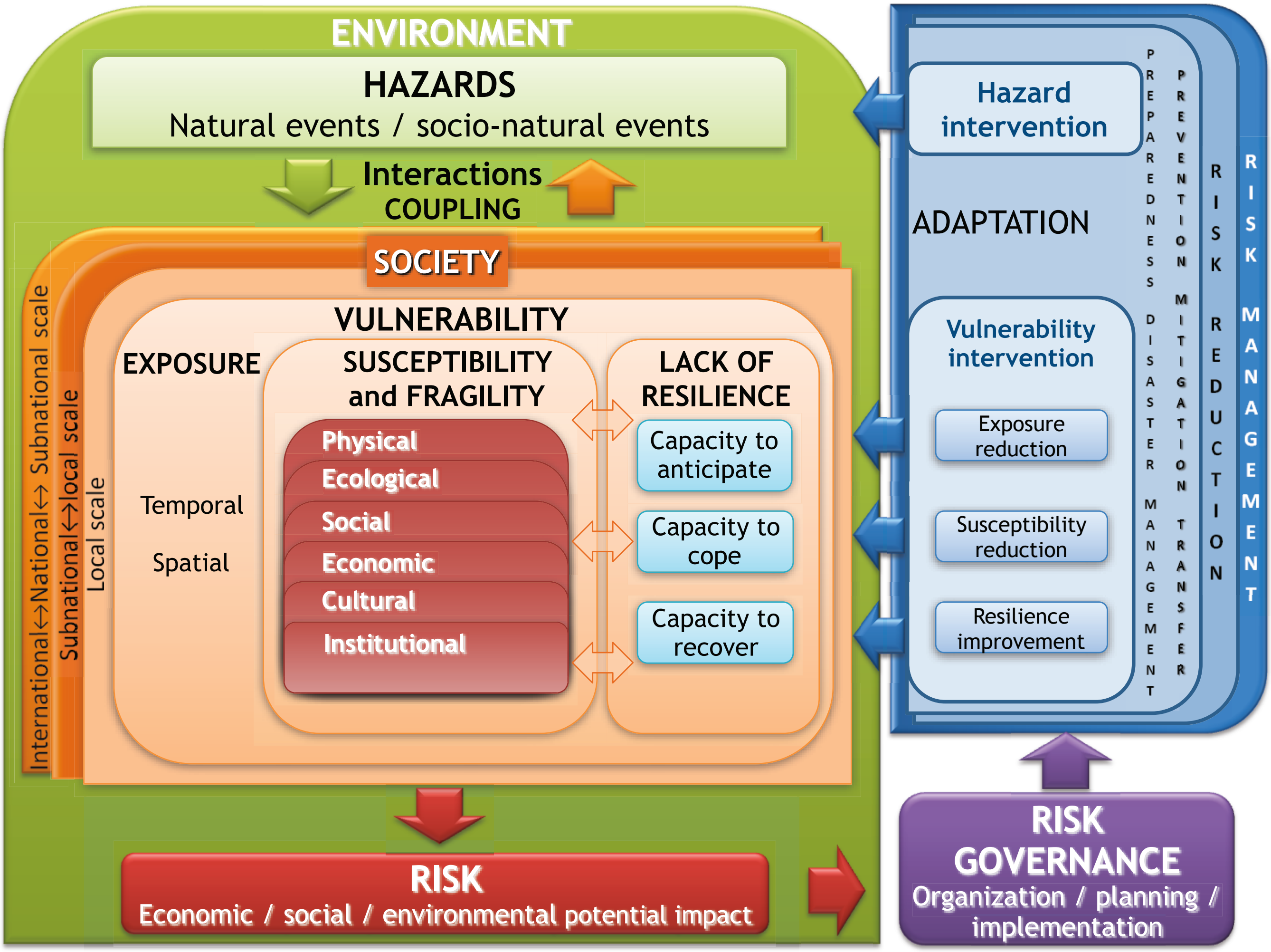
Just as the term 'resilience', the concept of capacities relates to the possibilities and abilities to reduce harm under hazardous conditions. Hereby, 'coping capacity' rather deals with the short-term conservation and protection of the current system and institutional settings, whilst 'adapting capacity' denotes a longer-term and constantly unfolding process of learning (Birkmann et al. 2013).

Conceptual issues and dimensions of vulnerability

Just as there are numerous definitions of the term 'vulnerability', there exist many models and concepts that describe vulnerability in its relation to other terms, such as resilience, exposure or capacities, and that elaborate on vulnerability's key dimensions. The European project 'Methods for the improvement of vulnerability assessment in Europe' (MOVE) developed such a concept, which attempts to represent the multifaceted nature of vulnerability (Figure 2.10). In its central part, it identifies six thematic dimensions of vulnerability: the physical, the ecological, the social, the economic, the cultural and the institutional dimension. All of these dimensions have to be considered within a holistic vulnerability study. The majority of assets and systems exposed to hazard will exhibit more than one dimension of vulnerability and hence these dimensions need to be addressed more in detail for any assessment (Birkmann et al., 2013).

FIGURE 2.10

The MOVE framework to conceptualise vulnerability
Source: Birkmann et al. (2013)



This framework is particularly useful within the context of disaster risk since it embeds vulnerability in the wider framework of risk governance/ management and emphasises the various intervention opportunities that may be taken to reduce risk.

A key initial question when scrutinising vulnerability is who or what is vulnerable to what type of threat or hazard. This leads to the question of how the interactions between hazards and vulnerabilities look like. In fact, there are significant differences in the way the various factors that determine vulnerability are linked or connected to different types of hazards. Typically, physical characteristics of elements at risk are directly linked to a particular hazard. For example, the degree to which a building withstands an earthquake is directly linked to the type of building material used. However, a great level of resistance related to earthquakes as a result of building material does not automatically imply that the ability to resist a flood event is similarly high. On the other hand, the predisposition to be adversely affected due to the economic, sociocultural or political-institutional susceptibilities is to a large degree hazard independent. A community, for instance, with a well-working emergency response system and a strong social network is better forearmed against any type of hazardous event than a community with corrupt public authorities and disrupted internal linkages (Brooks, 2003; Schneiderbauer and Ehrlich, 2006; Cardona et al., 2012).

Transferring these rather theoretical concepts into operational vulnerability assessments in practice results in a number of challenges. Most importantly, the majority of non-physical aspects of vulnerability are not measurable in the way in that we are able to determine temperature or people's income. Consequently, alternative methods for assessing vulnerability are applied. They can be quantitative or qualitative or a mix of both (see Section 2.3.4). Widely applied and accepted tools comprise vulnerability curves predominantly used for assessing physical vulnerabilities and the use of (proxy-) indicators, particularly to estimate the vulnerability of non-physical dimensions (for example social, economic or institutional vulnerabilities). Here, indicators are used to communicate simplified information about specific circumstances that are not directly measurable or can only be measured with great difficulty (Meyer, 2011). At local level, where spatial data and statistics often do not exist in sufficient resolution, expert opinions as well as participatory, community- based approaches play a major role in vulnerability assessments.

Power relations, cultural beliefs, the attitude towards risk- reduction efforts or the willingness and capacity to learn from previous events are essential for the degree of preparedness of a population. Related information can be found in story lines rather than in statistics. Another challenge lies in providing evidence about the degree of vulnerability and its causes. Vulnerability bears witness only in the aftermath of an event when damage and loss are realised. Loss and damage data, though strongly depending on the magnitude of the hazard itself, are therefore important data sources for vulnerability assessments and/or for the validation of assessment attempts (see Subchapter 2.4).

Due to the conceptual complexity and methodological challenges connected with vulnerability, the uncertainties of vulnerability assessments and their results is a topic of ongoing discussion. The uncertainties are an aggregation of uncertainties from several sources. They include limitations in knowledge about the socioecological systems that the vulnerable elements are part of as well as inaccuracies of empirical data and limitations of models applied for vulnerability assessments.

Uncertainty can be classified in many different ways. One possibility is to subdivide it into 'aleatory uncertainty', which represents the variability of the properties of concern, and 'epistemic uncertainty', which stems from limited knowledge. A sophisticated estimation of uncertainties is usually a difficult and costly exercise. Hence, the level of complexity and sophistication and the effort and resources to be spent should be in line with the risk management issue and correspond to the level of detail needed.

2.3.1.3 State of the art and research gaps

The number of existing theoretical frameworks and concepts related to various aspects of vulnerability is striking. Future work should focus on the translation of these concepts into action, namely by developing easy-to-use tools to implement vulnerability studies that yield useful results for the stakeholder and user. At least within Europe, a set of standardised methods for defined purposes at certain scales would help to monitor changes over time and to compare vulnerability patterns spatially. The respective activities need to consider the developments of other relevant fields of action such as climate change adaptation or sustainable development.

The awareness of the significance of vulnerability for DRM has significantly increased over the last decades. Nevertheless, the importance of underlying triggering factors of vulnerability and not directly tangible aspects such as the cultural and institutional dimension requires further attention.

2.3.2 System and systemic vulnerability

In order to advance the understanding of vulnerability and its dynamics as well as to set appropriate policy agendas, it is crucial to look at how the vulnerability dimensions interact at different spatial, temporal and functional scales (Cardona et al. 2012).

The fact that our modern world is increasingly interconnected calls for systemic approaches when assessing vulnerabilities and risks, which take into account feedback loops and cascading chains of impacts

In particular, analysing vulnerability in the framework of sustainable development or climate change adaptation requires considering the interactions between human and natural systems.

2.3.2.1 System dynamics affecting vulnerability

Vulnerability is a dynamic concept (Cardona et al. 2012) and thus varies in space and time. Trends in exposure and vulnerability are influenced by changes in the demographic, economic, social, institutional, governance, cultural and environmental patterns of a system (Oppenheimer et al. 2014). Taking demography as an example, the current trend of an ageing population that characterises developed countries has considerably influenced people's vulnerability to heat stress, as shown by the high death toll paid by the elderly during the 2003 heatwave event in Europe (Robine et al. 2008).

Another example is the concentration of assets and settlements (and economic activities) in hazard-prone areas due to population growth and the lack of related spatial planning. At a first view this phenomena simply represents increased exposure values. At a closer look, it is strongly linked to vulnerability. Hazard-prone areas are in general characterised by lower land values and are thus occupied by low-income households. The scarcity or non-existence of infrastructure, services, social protection and security in these sites eventually leads to 'socially segregated' urban development, which in turn generates new patterns of vulnerability and risk (UNISDR 2015b).

For instance, the most damaged areas during the 2010 floods in Bursa (Turkey) were those neighbourhoods characterised by the presence of informal settlements and occupied by low-income families (Tas et al. 2013).

Another aspect of systemic vulnerability is the dependence of human societies on ecosystem services, particularly those regulating climate, diseases and providing buffer zones (Millennium Ecosystem Assessment 2005). For example, coastal wetlands increase energy dissipation of storm surges, dampen wind-driven surface waves, modify wind fields and reduce the exposure of (and thus protect) people and physical assets in the hinterland. Moreover, provisioning services include food, raw materials, fresh water and medicinal resources, the availability of which determines well-being and thus can strongly influence the socioeconomic vulnerability profile of a community. Consequently, ecosystem-based adaptation approaches have been applied in DRM to address potentially hazardous processes such as flash floods, heat waves, sea level rise, increasing water scarcity, etc.

2.3.2.2 System criticality

Globalisation has made communities and nations interdependent in a number of realms, including politics, economy, culture and technology.
A systemic view postulates to consider those linkages within and without a socioecological system that may affect its vulnerability, thus drawing attention to wider human and environmen-

tal processes and phenomena (Turner et al. 2003). In concrete terms, this means that systems and their populations are not only affected by hazards to which they are physically exposed but also — by means of cascading effects — to those experienced elsewhere. Recent disasters such as the eruption of Eyjafjallajökull in Iceland (2010), the floods in Thailand (2011), the Great East Japan Earthquake (2011) and Hurricane Sandy in the United States (2013) called attention to the severe effects of such cascades of disasters.

Cascading disasters can be exemplified by the vulnerability of critical infrastructure (Pescaroli & Alexander 2016). When in 2003 a tree fell on a Swiss power line, causing a fault in the transmission system, 56 million people in Italy suffered the effects of the worse blackout in the country's history. 30 000 people were trapped on trains and many commercial and residential users suffered disruption in their power supplies for up to 48 hours (Johnson 2007). At a larger scale, failures in the global supply chain highlight how the vulnerability of one system may depend on the resilience of another system working in far spatial distance.

The Swedish company Ericsson experienced substantial loss due to the vulnerability of a subsupplier. A 10-minute fire at Philips' plant in New Mexico, caused by a lighting hitting the electric line, translated into a loss in phone sales of about EUR 375 million (Jansson 2004).

This was mainly because Ericsson took no action after Philips' reassurance about production returning on track in a week — which was not the case. On the contrary, Nokia, another big Philips customer, promptly switched supplier and it even re-engineered some of its phones to accept both American and Japanese chips. By doing so, it raised its profits by 42 % that year and managed to acquire new market shares (Economist Intelligence Unit 2009). The Ericsson–Nokia example underscores the fundamental role played by coping capacity in reducing the adverse effects of experienced hazards. Moreover, it calls for drawing attention not only to the triggering event when considering cascading disasters, but more importantly to how vulnerabilities of different system's components may align and thus amplify impacts (Pescaroli & Alexander 2016).

2.3.2.3 State of the art and research gaps

Disaster risk research often remains fragmented in a number of disciplines and focused on single hazards (Cutter et al. 2015), with limited interaction with other relevant communities. Research adopting a coupled human-environmental system approach in framing vulnerability has contributed to the integration of separate domains (Cardona et al. 2012).

Namely, the approach of ecosystem-based adaptation has transferred this holistic view into practice. Yet, the level of trans- and interdisciplinarity that would be required to implement truly systemic approaches in vulnerability assessment is rarely achieved. Hence, future applied research should follow an approach of coproduction of knowledge and need to integrate relevant disciplines. Relevant university education and training programmes should prepare young scientists and practitioners accordingly.

2.3.3 Vulnerability within the context of changing climate conditions

Climate change is one of the most prominent examples of an external biophysical stressor putting coupled human-natural systems at risk and the vulnerabilities to changing climate conditions has been the focus of many assessment studies. Originally, the understanding of 'vulnerability' in the community of climate scientists differed from that of the disaster risk research by encompassing the hazard component itself. That is, the projected change of relevant climate parameters was seen as part of the system's vulnerability to climate change (IPCC 2007).

Knowledge on climate change is growing fast, but standardised vulnerability assessment approaches are lacking. Vulnerability assessment must consider changing socioeconomic, political and organisational conditions that determine possible vulnerability pathways.

The Intergovernmental Panel on Climate Change (IPCC) special report, Managing the risks of extreme events and disasters to advance climate change adaptation (IPCC, 2012a), and later on its fifth assessment report (IPCC, 2013) have introduced the concept of 'climate risks' and have hence worked towards converging the concepts of both communities. The currently ongoing integration of climate change adaptation and disaster risk- reduction approaches leads to an increase of knowledge and has the potential to foster network building and to develop more efficient policies. A respective report is under preparation under the lead of the European Environment Agency (EEA).

The IPCC's fifth assessment report identifies several ways in which increasing warming and climate-related extremes can have an impact on a socioecological system and focuses in particular on those complex interactions between climate and such systems that increase vulnerability and risk synergistically (Oppenheimer et al., 2014). One of them is the negative effect of climate change on human health, which results from a number of direct and indirect pathways.

Direct biological consequences to human health can derive from heatwaves, extreme weather events and temperature-related concentrations of pollutants; yet most of the impacts will be indirectly triggered by warming-induced changes in environmental and social conditions (Mc Michael 2013) and are hence in their extent determined by respective vulnerabilities. Moreover, climate change induced adverse impacts on crop yields' quantity and quality can exacerbate malnutrition (Met Office & WFP, 2014) and thus contribute to new or stronger vulnerabilities to a range of diseases.

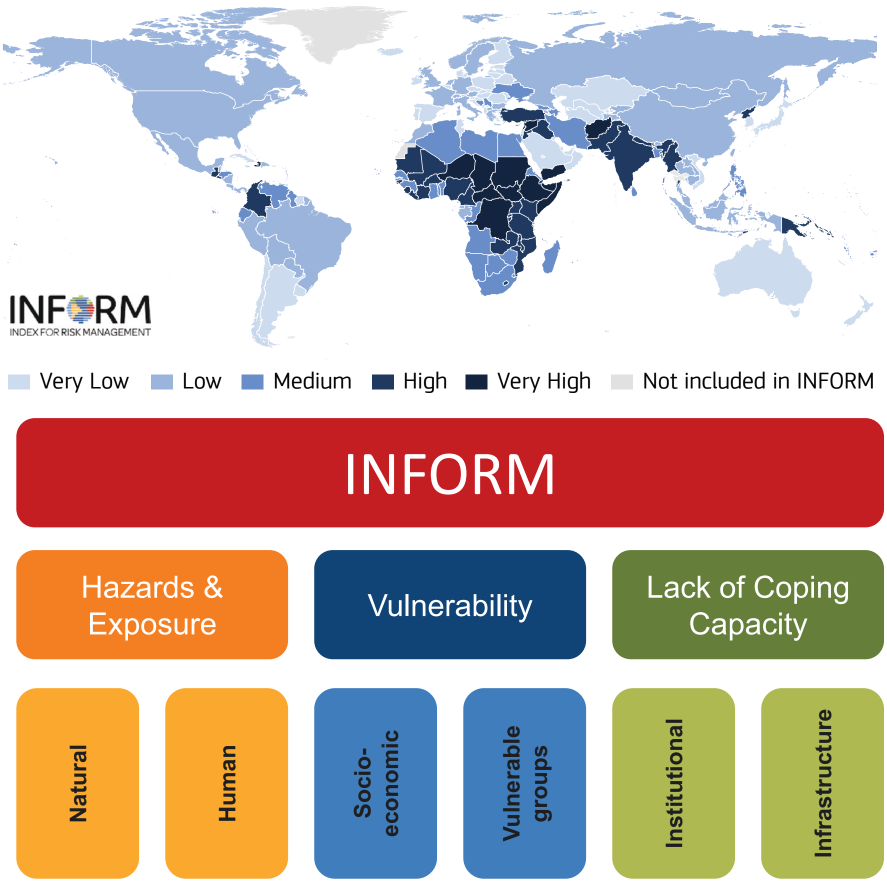
The assessment of climate-related risks and the identification of respective key vulnerabilities needs to consider the variety of these possible direct and indirect impacts. Useful tools to tackle this challenge are so-called impact chains, which represent cascading cause-effect relationships and allow for structuring assessment processes and the prioritisation of fields of action (Schneiderbauer et al., 2013; Fritzsche et al., 2014). Impact chains have, for example, been developed and applied by the ci:grasp adaptation support platform (n.d.) and the latest German climate change vulnerability study (Buth et al., 2015).

2.3.3.1 Vulnerability and climate change in Europe

At European level, climate change is recognised as an important driver of risk due to both climate extremes (for example heavy precipitation events

FIGURE 2.11

Global maps of vulnerability index calculated by INFORM (upper left) approaches and the identified sub-components of risk and vulnerability left and the WorldRiskIndex on the bottom right.
Source: BEH and UNU-EHS (2016), INFORM (n.d.)



or storms) and slow onset events of long-term duration (for example sea level rise or glacier retreat) Climate change will also have positive impacts in Europe in specific sectors and in certain regions (for example agriculture and tourism in northern Europe). In this chapter we concentrate on potential adverse impacts that require actions to reduce related risks.. Though all the countries in the EU are exposed to climate change, the related impacts vary depending on differences in climate conditions but also in vulnerabilities and degree of exposure (EC, 2013). Many EU Member States have based their national adaptation strategies on studies about risks and vulnerabilities to climate change, for example the United Kingdom in 2016 (UK, 2016), Germany in 2015 (Buth et al., 2015) and the Netherlands (PBL, 2012). At European level, respective studies have been implemented by the European Observation Network, Territorial Development and Cohesion (ESPON) in 2011 (EPSON, 2011) and the EEA in 2012 (EEA, 2012) and 2016 (EEA, 2017), as well as the European Commission in 2014 (Ciscar et al., 2014). The EEA hosts the European climate adaptation platform website that represents the knowledge hub for climate change risks and adaptation in Europe (Climate-ADAPT, n.d.).

Some key vulnerabilities related to climate change identified by these reports are:

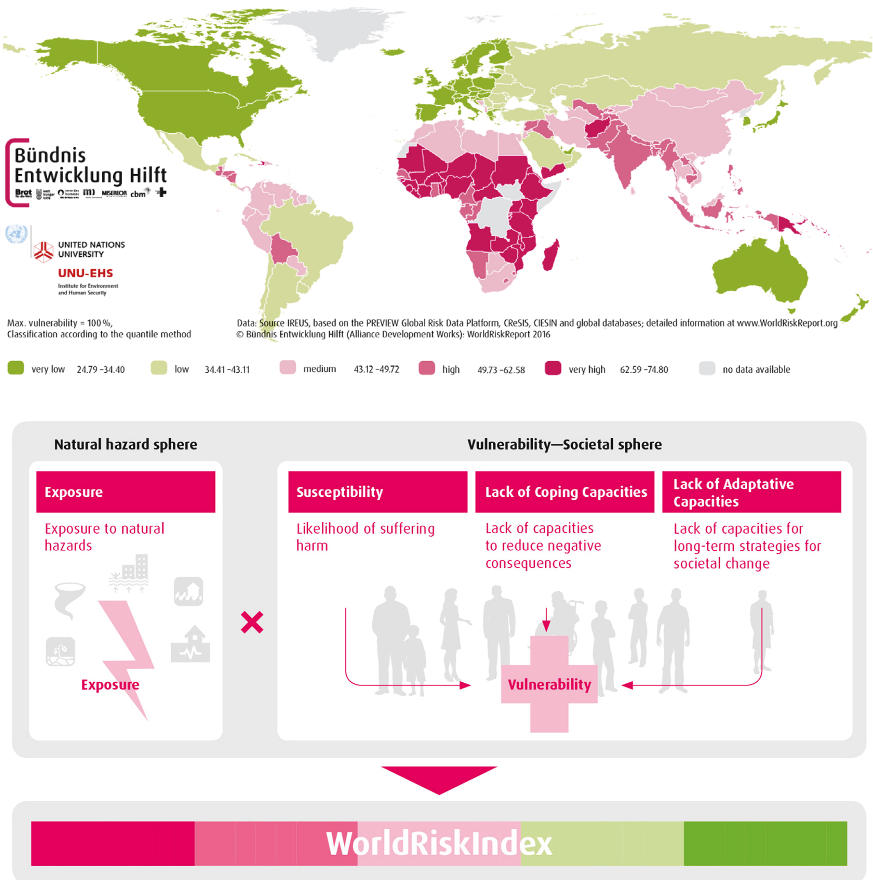
- demographic change / aging population;
- population growth in low- lying urban agglomerations;
- vulnerability of (critical) infrastructure to warming and floods;
- increasing dependency on electricity, particularly linked with the increasing internationalisation of power grids.

2.3.3.2 State of the art and research gap

The knowledge about future climate conditions is vast and continues to increase. There are numerous studies scrutinising climate change impacts and vulnerabilities. However, most of them have been carried out in a static context and they have not considered future socioeconomic developments resulting in changes of land use, urbanisation or demography. Besides climate scenarios, climate risk studies should aim to integrate vulnerability pathways.

Europe-wide climate risk assessment should further be supported and coordinated with the results from national and subnational studies, where appropriate. A certain level of standardisation is desirable in order to allow for comparison in space and time.

and WorldRiskIndex (upper right). The respective underlying conceptual are shown in the lower part representing the INFORM index on the bottom

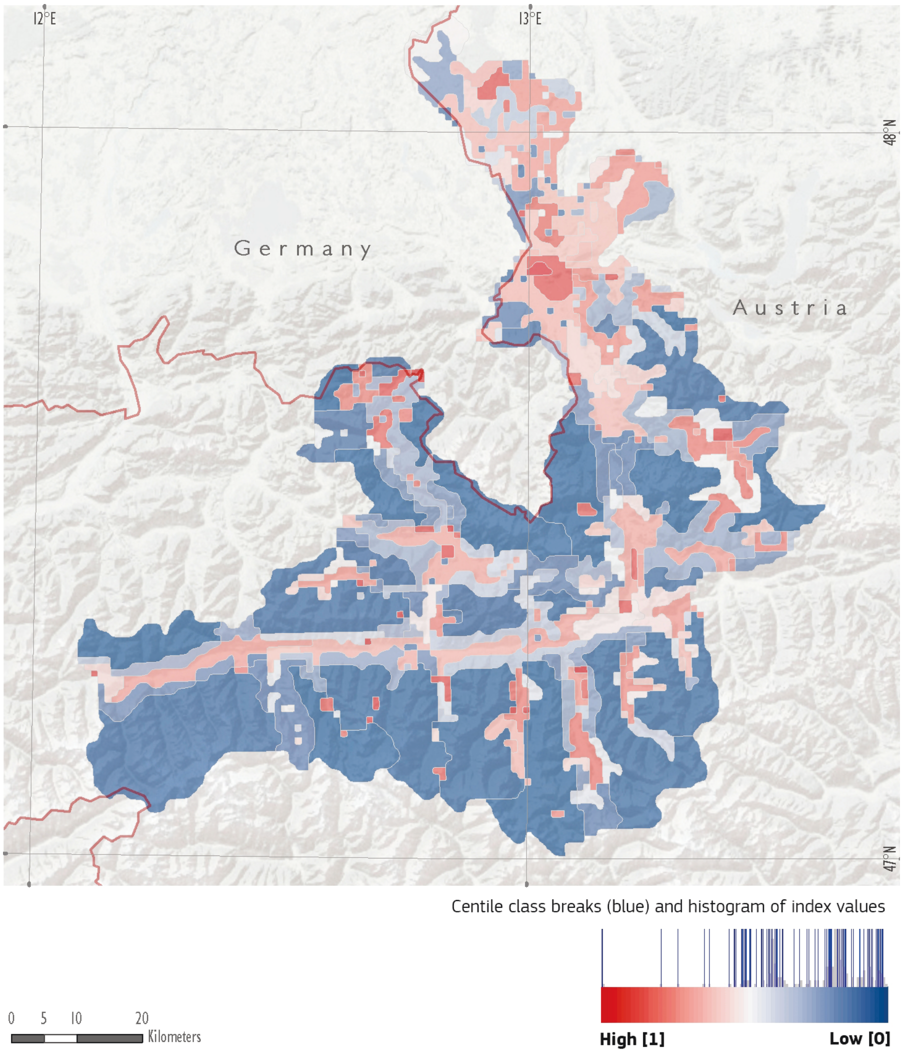


2.3.4 Approaches to assess vulnerability

Researchers and practitioners apply quantitative, semi-quantitative, qualitative and increasingly mixed-methods approaches in order to assess vulnerability. Whether an approach is best suitable strongly depends on the objective and the scope of the assessment (e.g. understanding root causes, identification of hotspots, trend analysis or the selection of risk- reduction measures), as well as on the temporal and spatial scale; there is no 'one size fits all' approach.

FIGURE 2.12

Social vulnerability to floods in the Salzach river catchment, Austria. Source: Kienberger et al. (2014)



Qualitative vulnerability analyses are based on experts' estimates. They are particularly useful if time and resources for the study are limited and if accessible data / information is not sufficient for quantitative analysis of complex phenomena. Qualitative assessment carried out with participatory techniques, such as interviews or focus group discussions, is particularly important for work at local/community level and can reveal context-specific root causes for vulnerabilities. Quantitative assessments are often based on statistical analysis exploiting data about loss and damage related to certain hazards (see Section 2.3.4.1). The most widely employed alternative to this is the application of indicator-based approaches, which ideally allows assessing patterns and trends of vulnerability across space and time. The multifaceted nature of vulnerability cannot be adequately represented by a single variable (e.g. income per capita). Consequently, the generation of composite indicators has gained importance for grasping such complexities. It allows for combining various indicators into a vulnerability index and helps to translate complex issues into policy-relevant information.

At global level, there are a number of composite indicators to assess disaster risk, which represent vulnerability as one of the risk's dimensions next to hazard and exposure, for example the WorldRiskIndex (Welle and Birkmann, 2015; BEH and UNU-EHS, 2016) and the INFORM Index (De Groeve at al., 2014; INFORM n.d.). Both are continuously updated multi-hazard risk indices aiming to support disaster risk reduction. The WorldRiskIndex is a means for understanding natural hazard related risks including the adverse effects of climate changes whilst INFORM is a tool for understanding risks to humanitarian crises and disasters. Conceptually, both indices are very similar. Their methodologies are presented in Figure 2.11. In the WorldRiskIndex, the vulnerability part comprises the components of susceptibility, coping capacity and adaptive capacity, which are represented by 23 indicators. In INFORM, vulnerability and lack of coping capacity are divided into two separate dimensions, which are described by 31 indicators. Figure 2.11 shows the countries' vulnerability scores based on data from 2016 calculated using the INFORM approach (left) and the WorldRiskIndex approach (right). Below these maps, the respective approaches and sub-components are visualised. Both indices started with an approach at nation-state resolution and global scale but strive for more sub-national applications of their methodology (Wannewitz et al., 2016).

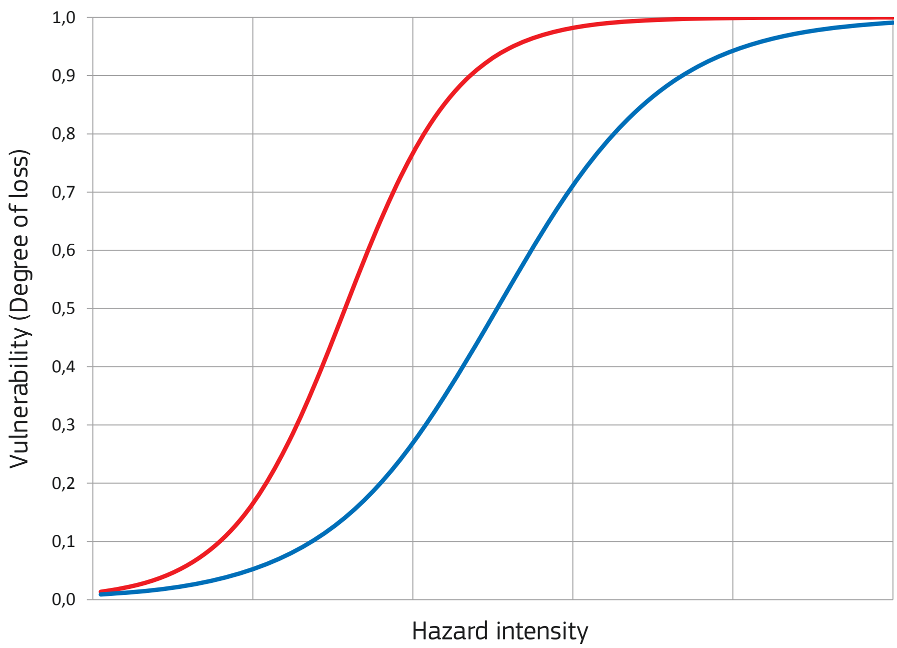
In Europe, a range of assessments have used spatial approaches, such as spatial multicriteria analysis or composite indicators to create maps at subnational level that facilitate the identification of hotspots and offer information for place-based intervention planning. For instance, a number of studies have investigated vulnerability in the context of river floods at different spatial scales. Examples include assessments: (1) in Vila Nova de Gaia, a flood-prone municipality in northern Portugal (Fernandez et al. 2016); (2) along the rivers Rhine, Danube and Elbe in Germany (Fekete 2009); or (3) in the Salzach catchment in Austria (Kienberger et al. 2014) (Figure 2.12). Using indicator-based approaches, the three case studies identify a set of social (e.g. age, education and gender), economic (e.g. income, employment and dependency), organisational and institutional (e.g. early warning systems (EWS), access to health services, proximity to first responders, etc.) indicators and aggregate them into a composite index of vulnerability.

Composite indicators have the advantage to represent complex phenomena in a single value. If necessary, the underlying indicators or subcomponents of the index can be visualised separately to support the understanding of which factors contribute most to a positive or negative situation in the aggregated result (Hagenlocher et al. 2013). On the other hand, composite indicators are always data driven and might conceal crucial aspects that are not or cannot be expressed in numbers and statistics.

In recent years, there is an increasing number of studies aiming to understand and analyse vulnerability in multihazard settings. For example, Welle et al. (2014) present an approach for the assessment of social vulnerability to heat waves and floods as well as institutional vulnerability to earthquakes in the city of Cologne, Germany. While different sets of vulnerability indicators are used and aggregated to assess vulnerability to heat waves (e.g. age, unemployment, place of origin,

FIGURE 2.13

Generic quantitative vulnerability functions showing vulnerability (i.e. degree of loss) as a function of hazard intensity. The red curve represents a more vulnerable element and the blue curve a less vulnerable element. Source: courtesy of authors



etc.) and floods (age and occupancy rates per household), institutional vulnerability was evaluated using qualitative information obtained from a series of stakeholder consultations. Acknowledging the fact that communities are often affected by multiple hazards — combined, sequentially or as a cascading effect —, these studies present an important step towards providing solutions for real-world challenges.

2.3.4.1 Quantitative vulnerability functions

Potential damage to physical assets and loss of human lives are often assessed using quantitative vulnerability functions. These functions take into account the intensity of the hazard and the properties of the exposed elements. The intensity expresses the damaging potential of the hazard. Properties represent the resistance of the exposed elements such as building material and maintenance level. Vulnerability functions are widely applied to illustrate the relationship between hazard characteristics and fatalities and damage. Generic vulnerability functions are shown in Figure 2.13 and refer to physical vulnerability, described as 'the degree of loss to a given element, or set of elements, within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss)' (UNDRO 1984).

Vulnerability functions may be subdivided into fatality/mortality functions and damage functions (the latter denoted and formulated in different ways, e.g. loss functions, susceptibility functions and fragility functions). Damage functions are mainly based on empirical data collected in the aftermath of an event. Damage functions, in particular functions relating building damage to water depth, have a long tradition in the context of flood damage evaluation (Meyer et al. 2013). Physical vulnerability of buildings can also be assessed by physical models or by use of expert judgement. For some hazard types, fatality or mortality functions are developed to determine the death ratio for a single hazard parameter, e.g. water depth or earthquake magnitude. This allows the estimation of numbers of fatalities occurring at, for example, a certain water level. However, the development of fatality functions goes along with a high degree of uncertainty, which stems from the variety of physical and human parameters influencing the loss of life. For example, water depth may not be the only and most relevant intensity measure. Aspects such as flow rate, flood duration or sediment transport might be equally as important.

The most appropriate methodology to assess vulnerability strongly depends on the purpose and the context, as well as the temporal and spatial scales; there is no 'one size fits all' approach.

For quantitative physical vulnerability assessment, one can apply existing vulnerability curves, which are appropriate for the specific hazard and the exposed elements (e.g. building types) in study. Vulnerability curves have been developed for several types of natural hazards, such as wind storms, landslides, floods, tsunamis and earthquakes. There are curves expressing loss within the built environment as well as loss of human lives. Most of the curves are developed from empirical data and accordingly fit well with previous events in the area where the data was collected. For other locations a calibration or validation of the model is necessary prior to use. Validation is also needed for physical or analytical vulnerability functions.

Application of vulnerability functions is useful in several phases of the risk management, such as risk assessment and risk treatment. Risk analysts, scientists, stakeholders and decision-makers could be users of vulnerability functions with the purpose to provide input to:

- decisions about the question of whether risks need to be treated or about issues such as the prioritisation of risk treatment options of different areas and of different hazard types;
- identification of appropriate and optimal risk- reduction measures;
- financial appraisals during and immediately after a disaster as well as budgeting and coordination of compensation (Merz et al., 2010).

Alternatives to vulnerability curves are fragility curves, which also express the uncertainty in the physical vulnerability. Fragility curves have been widely applied in probabilistic risk and vulnerability assessment, in particular for earthquake risk (Hazus n.d.), but recently also for landslide risk assessment. These functions describe the probability of exceeding different damage states for various intensities. In a recent study on seismic risks in the city of Barcelona, Spain, a physical vulnerability assessment approach was first carried out based on vulnerability functions for different building types (e.g. unreinforced masonry or reinforced concrete, steel and wood buildings). In a second step this was combined with a probabilistic analysis of the seismic hazard into a seismic risk assessment for buildings across the city (Carreño et al., 2014). The authors also considered conditions related to social fragility and lack of resilience that favour second order effects when a city is hit by an earthquake. Factors such as population density, population with poor health or social disparity were used as proxies for social fragility. In addition, the operating capacity in case of an emergency, the state of development or the access to health services were used as indicators of lack of resilience and combined in an overall urban seismic risk index (Carreño et al., 2007). The results show that the population in the central parts of Barcelona lives at a considerably higher risk than those living on the outskirts of the city.

2.3.4.2 State of the art and research gaps

Indicator-based assessment methods have proved to support the drafting and prioritisation of disaster risk- reduction measures and strategies as well as the allocation of resources. Several challenges exist with respect to the dependency on data availability and quality, the validation of the applied methodology and related uncertainty analysis (Hinkel, 2011).

Vulnerability curves are widely applied for physical vulnerability assessment. Future activities should focus on the development of a repository of vulnerability curves with user guidelines for different hazard types and different types of assets. Research should work on the development and use of multiparameter vulnerability functions that are transferable, i.e. valid for different building types, and applicable for vulnerability changing over time and for multirisk scenarios.

In order to fill these gaps, more data are required for improving and calibrating existing models as well as for proposing new empirical vulnerability models (see Subchapter 2.4). Data collection and analysis should be extended and streamlined through the use of remotely sensed data and geographic information system technology. The potential of Copernicus services and particularly of Sentinel data has not been fully exploited by the disaster risk community.

An additional challenge lies in the forward-looking nature of vulnerability. That is, vulnerability assessment needs to take into account those factors and processes that may not yet have become evident in past disaster situations. This is particularly valid in highly dynamic environments where both socio-natural hazards and vulnerability patterns might undergo rapid changes in the near- and mid-term future (Garschagen 2014).

The importance to integrate uncertainty in vulnerability assessment has often been underlined but remains an issue of concern still today.

2.3.5 How vulnerability information is used in practice

The IPCC acknowledges DRM as a process that goes beyond DRR (IPCC 2012b). Decisions to reduce disaster risk must be based on a sound understanding of the related vulnerabilities.

A requirement that has clearly been articulated in the SFDRR (UNISDR 2015b) as one of four main priorities for action in the years to come.

2.3.5.1 Vulnerability in disaster risk management: from knowledge to action

Complementing hazard analysis, vulnerability studies generate information of relevance for various aspects of risk reduction and adaptation strategies, emergency management and sustainable territorial planning. They are of importance for all phases of the DRM cycle covering short-term response as well as long-term preparedness or recovery. Correspondingly large is the field of potential users of vulnerability information, including public administration staff who are responsible for civil protection or spatial planning, actors in the field of insurance, private companies running critical infrastructure, the civil society and, finally, any individual. One way of grouping the various purposes of vulnerability studies and their main users is to classify them according to spatial scale. Extending the examples presented above, Table 2.1 provides

TABLE 2.1

Overview of vulnerability assessments, their main objectives and potential users at different spatial scales. Source: courtesy of authors

Scale	Main objective	Examples	Potential users
Global	Identification of spatial hot spots; allocation of resources; awareness raising	The vulnerability components of the following risk indices: INFORM index (De Groeve et al. 2015); World Risk Index (BEH & UNU-EHS 2016); Disaster Risk Index (Peduzzi et al. 2009); Natural Disaster Hotspots index (Dilley et al. 2005)	International organisations (including donors); international non-governmental organisations (NGO); regional intergovernmental organisations
		Notre Dame Global Adaptation Index (ND-GAIN n.d.)	
International/ regional	Identification of spatial hot spots; allocation of resources; awareness raising	The vulnerability component of the INFORM Subnational risk index for the Sahel and the Greater Horn of Africa (INFORM subnational models n.d.)	International organisations (including donors); international NGOs; ROI
		Vulnerability to climate change in Europe (ESPON 2011); climate change vulnerability mapping for Southeast Asia (Yusuf & Francisco 2009)	
National / subnational	Identification of hot spots; development of risk reduction / adaptation strategies; allocation of resources; awareness raising; advocacy	The vulnerability component of the INFORM Subnational risk index (INFORM subnational models n.d) for Lebanon and Colombia, World Risk Index subnational for the Philippines (Wannewitz et al. 2016); Social Vulnerability Index for the USA (Cutter et al. 2003)	International organisations (incl. donors); international /national / local NGOs; national, subnational and local governments and public administration
		Numerous studies in Europe. For an overview of work related to climate change, see Prutsch et al. 2014	
Local	Identification of root causes; strengthening capacities of local actors; empowering communities	For an overview of vulnerability assessments in Europe with respect to natural hazards, see Birkmann et al. 2014;	International organisations (incl. donors); international / national/ local NGOs; national, subnational and local governments and public administration- affected communities
		A semi-quantitative assessment of regional climate change vulnerability by Kropp. et al. 2006	

an illustrative overview of selected vulnerability assessments, their main purposes and potential users at different spatial scales.

Vulnerability assessment is used to support stakeholders and policymakers in prioritising various risks, in identifying root causes and spatial hotspots and in developing risk reduction strategies and measures.

The complexity of vulnerability and the wide range of possible applications of assessment studies require considerable effort to define the studies' scope (objective, target groups, spatial and temporal scale, spatial resolution of results, etc.). In practice, vulnerability studies have benefited from pursuing a process of co-production of knowledge. The integration of scientists, practitioners and potential users in the process of a vulnerability assessment right from the beginning usually results in a higher level of acceptance of their results. They are also more likely to be used in decision- and policymaking. An example is the latest vulnerability assessment for Germany within the scope of which a network of national authorities was created and which participated in all important decisions (Greiving et al., 2015).

2.3.5.2 Conclusions and key messages

Over the past decades, vulnerability research has made considerable progress in understanding some of the root causes and dynamic pressures that influence the progression of vulnerability and raised awareness that disasters are not natural but predominantly a product of social, economic and political conditions (Wisner et al. ,2004).

Vulnerability assessments are a response to the call for evidence by decision-makers for use in pre-disaster risk assessment, prevention and reduction, as well as the development and implementation of appropriate preparedness and effective disaster response strategies by providing information on people, communities or regions at risk.

The following steps are proposed to further improve vulnerability research and related applications with the final aim to inform policymakers to most appropriately:

- co-produce knowledge in a transdisciplinary environment;
- evaluate and present inherent uncertainties;
- integrate intangible but crucial factors into quantitative assessments;
- develop and apply methods that allow for considering cascading and multirisks;
- combine vulnerability scenarios with (climate-) hazard scenarios when assessing future risks;
- empower communities to better understand and reduce their vulnerability in order to make them more resilient to identified hazards;
- design and facilitate multilevel and cross-sectoral feedback loops between public, practitioners and policymaking bodies (local, regional, national and European) and other stakeholders;
- standardise vulnerability assessment approaches in order to allow for more comparison (in space and time);
- work on improved evidence within vulnerability assessment — this requires continuous effort to improve loss and damage data.

Partnership

The comprehensive analysis and assessment of vulnerability requires an interdisciplinary approach involving both natural and social sciences. In addition, in order to foster sustainable and efficient vulnerability reduction strategies and measures, an approach to produce knowledge co-productively is desirable. This calls for a partnership with affected communities, practitioners and decision-makers. A stronger link and enhanced interaction with other relevant communities is desirable, namely climate change adaptation, natural resource management, public health, spatial planning and development.

Knowledge

The determination of risk often remains hazard centred and hazard specific and does not consider vulnerability appropriately. Vulnerability assessment has tended to be mostly quantitative in nature. Cultural aspects as well as formal (procedures, laws and regulations) and tacit informal (values, norms and traditions) institutions play a fundamental role as both enabling or limiting factors of resilience and have not gained sufficient attention. A challenge is the need to consider local data and information in order to account for small-scale specificities of vulnerability. Present databases on damage and loss caused by natural hazards should be standardised and extended to support evidence building in vulnerability assessment. Existing barriers in the co-production, exchange and use of knowledge have to be understood and minimised.

Innovation

In recent years, improved approaches to assess vulnerability by statistical analyses or indices have been established. Fostering the integration of Earth observation data and technology to detect changes would improve the possibility to represent some of the dynamic aspects of vulnerability. Further improvement requires enhanced event and damage databases and more sophisticated methods for potential future vulnerability pathways and their integration into risk scenarios. The challenge to integrate qualitative information, which often contains crucial facts, needs to be addressed. Observation data and technology to detect changes would improve the possibility to represent some of the dynamic aspects of vulnerability. Further improvements require enhanced event and damage databases and more sophisticated methods for potential future vulnerability pathways and their integration into risk scenarios. The challenge to integrate qualitative information, which often contains crucial facts, need to be addressed.