INPUT PAPER

Prepared for the Global Assessment Report on Disaster Risk Reduction 2015

NATURAL HAZARDS:

Direct Costs and Losses Due to the Disruption of Production Processes

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November 30, 2013

Introduction

In recent decades, we have witnessed a significant increase in direct damage from natural hazard worldwide. A further increase is expected due to the ongoing accumulation of people and economic assets in risk-prone areas, the possibly increasing vulnerability of our modern societies, and the effects of climate change on the severity and frequency of drought events, for instance. To mitigate the impact of natural hazards on economies and societies, better risk assessment and management are needed.

Traditional approaches to protect against natural hazards are generally characterized by a safety mentality. Protection focuses on design criteria and does not analyze in detail the complete spectrum of possible events, failure scenarios, and protection objectives. This traditional safety (or "promise of protection") approach is increasingly being replaced by what is referred to as "risk management." Risk management is based on a comprehensive analysis not only of hazard, but also of possible consequences, and also involves appraisals of potential risk-reducing measures. In this context, risk is commonly defined as damage that occurs or will be exceeded with a certain probability in a certain time period (e.g., Merz et al., 2010).

Within this evolving context of decision making in risk management, damage assessments have gained growing importance. Knowledge of potential direct damage from natural hazards is important because this knowledge makes it possible to identify economic assets at risk, examine the effectiveness of hazard mitigation strategies, and calculate insurance premiums (Messner et al., 2007).

Definitions of different cost categories still vary between hazard communities, and concepts are a matter of continuous research. For this study, cost categories are defined as follows: Direct damage refer to losses that occur due to a direct physical impact of a hazard on humans, economic assets, or any other object. Examples are loss of life due to drowning; destruction of buildings, contents, and infrastructures due to landslides; and loss of crops and livestock due to droughts. Business interruption costs occur in areas directly affected by the hazard. Business interruptions take place if people are not able to carry out their work because their workplace is destroyed or not accessible due to a hazard; or if industrial or agricultural production is reduced due to water scarcity. Indirect damage occurs mainly outside of the hazard area, often with a time lag. Examples of indirect damage are negative feedbacks to the wider economy, for instance resulting from production losses of suppliers or the costs of traffic disruption (Parker, Green, and Thompson, 1987; Smith and Ward, 1998; Messner et al., 2007). These cost categories can all be further classified into tangible and intangible damage.

This study focuses on direct tangible damage[1] to economic assets and on losses due to the disruption of production processes, which occur due to impacts of natural hazards on all

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[1] Tangible damage refers to damage for which a market price exists, such as destroyed economic assets or damage to resource flows. Damage that is difficult to quantify in monetary terms because no market price exists, such as adverse health effects, loss of life, and damage to environmental goods or services, are referred to as intangible damage (Merz et al., 2010).

economic sectors.[2] As examples, it considers cost assessment methods for floods, droughts, coastal hazards, and Alpine hazards.

In spite of recent research in estimating direct damage and losses due to the disruption of production processes from natural hazards, robust, reliable approaches usable across Europe do not yet exist. Particularly in comparison with hazard modelling, simple approaches still dominate loss assessments, mainly because available data and knowledge of damage mechanisms are limited. Moreover, the diversity in methodological approaches makes it difficult to establish comprehensive, robust, and reliable costs figures that are comparable across different hazards and countries.

This study compiles and analyzes approaches to the assessment of direct costs and of losses caused by the disruption of production processes. It systemizes the methods used in different hazard communities, identifying similarities and differences, so that as much as possible can be learned from each hazard type. It also highlights knowledge gaps and research needs, and makes recommendations for cost assessment best practice.

Approaches to Estimating Direct Damage and Losses Due to Disruption of Production Processes

Assessing direct damage and losses due to the disruption of production processes generally consists of three steps (Merz et al., 2010; Messner et al., 2007):

1. Classifying elements at risk by pooling them into homogeneous classes
2. Conducting exposure analysis and asset assessment by describing the number and type of elements at risk and by estimating their value
3. Conducting susceptibility analysis by relating the relative damage of the elements at risk or the time period of interrupted business operations to the impact

Classification of Elements at Risk

Damage assessments can show varying degrees of detail, depending on the spatial and temporal scale of the analysis. While micro-scale assessments usually consider detailed and object-based information on houses, infrastructural elements, industry, commerce, or agriculture (Parker, Green, and Thompson, 1987; FEMA, 2011), meso- and macro-scale assessments usually consider aggregated asset categories such as land-use units (Wünsch et al., 2009; Merz et al., 2010; FEMA, 2011).

Because data and resources are lacking, assessing damage on the basis of individual objects is rare. Similar units or elements at risk are usually pooled together and classified as a single group. Most often, classifications of elements at risk reflect economic sectors, such as private households, agriculture, commerce, or industry (ICPR, 2001; Kreibich et al., 2007). This approach assumes that elements within an economic sector show comparable susceptibility characteristics and are also comparable with respect to production process and value added

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[2] The research for this paper was supported by the European Community's Seventh Framework Program through the Coordination Action Project CONHAZ-Costs of natural hazards, grant agreement no. 244159. This paper reflects the authors' views only and not those of the European Community.

(Kreibich et al., 2010; FEMA, 2011). An advantage of classifying elements at risk along economic sectors is the fact that economic data, which are needed for damage assessments, are often available on aggregated levels from national or regional statistical offices.

Exposure Analysis and Asset Assessment

Identifying assets at risk is usually done with the help of a geographical information system (GIS), by overlaying object or land-use data with hazard maps (Glade 2003; BUWAL 1999).

The respective values of the exposed elements need to be identified in order to derive quantitative damage estimates of the exposed assets. Although a number of approaches have been applied to estimate asset values for exposed elements, few risk assessment studies describe their approach in detail. A good overview of different approaches to estimating asset value, as well as a case study for Tyrol (Austria), is provided by Huttenlau and Stötter (2008). Merz et al. (2010) provide an overview of different estimation approaches and show that the spatial scale of the analysis, the availability of input data, and the required accuracy of the damage assessment all influence the level of detail considered. While micro-scale assessments, for instance, base their estimations on the construction costs of different building types (Blong, 2003), studies on the macro-scale use the gross capital stock of fixed assets in the exposed area (MURL, 2000).

Even though asset values are mainly defined by the type of element at risk, they can still vary in time and space. Variations in time occur, for instance, due to inflation, new investments, or innovations (Elmer et al., 2012). To take variations in time into account, asset values can be adjusted using price indices or by regularly updating the underlying database. Spatial variations can occur due to regional differences in asset values of the same object type, for example due to differences in material or labor costs.

In most models, monetary business interruption losses are modeled as losses of flows for a certain time period (Parker, Green, and Thompson, 1987; Booysen, Viljoen, and de Villiers, 1999). Flows are defined as the outputs or services of stocks over time (Rose and Lim, 2002). Often, the value added is used as a measure for the sum of flows in a company (Parker, Green, and Thompson, 1987; Penning-Rowsell et al., 2005). Thus, in order to estimate losses due to the disruption of production processes, the flows potentially affected by a hazard need to be established. On the micro level, the lost value added can be calculated using the total turnover of a company per day, which must be determined in a survey (Parker Green, and Thompson, 1987), or, when no survey can be administered, by using data from statistical offices (FEMA, 2011). On the meso-scale, losses can be derived using information aggregated on the level of economic sectors. For instance, the U.S. model Hazus-MH MR5 provides information on output per square foot per day for 33 occupancy classes, such as retail trade, hospitals, high technology, agriculture, and schools and libraries (FEMA, 2011). Data are derived from statistical offices such as the U.S. Bureau of Labor Statistics.

Susceptibility Analysis

After elements at risk have been classified and the assets exposed to hazard have been identified and assigned a respective value, the final step is to define their susceptibility. Susceptibility assessments and models for the assessment of direct damage and losses caused by the disruption of production processes are specific to the individual natural hazard.

A standard approach to define the susceptibility of elements at risk and to estimate direct damage is the use of damage (susceptibility) functions (Smith, 1994; Meyer et al., 2013). These functions define for the respective elements at risk the relationship between (on the one hand) hazard and exposure characteristics and (on the other) the damage that can be expected under the given circumstances. Numerous damage-influencing parameters can be taken into account to define the susceptibility of elements at risk.

There are two main approaches to developing the damage functions needed for flood risk assessment (Merz et al. 2010). First, damage functions can be empirically derived using observed flood damage data (e.g. Merz, Kreibich, and Lall, 2013), such as that contained in the HOWAS database (Merz et al., 2004) and its successor, the HOWAS 21 database (http://nadine-ws.gfz-potsdam.de:8080/howasPortal/client/start). Second, damage functions can be derived using a synthetic approach, in which experts from (for example) the insurance industry or engineers estimate the amount of damage that would occur to a specific element at risk under certain flood conditions (e.g. Penning-Rowsell et al., 2005).

Many studies evaluate damage of past drought events ex post, using self-report or media reports, or comparisons between drought and nondrought years (Martin-Ortega and Markandya 2009). These studies do not determine susceptibility to droughts by predefined relations between certain drought hazard and resistance parameters and expected damage. For the agricultural sector, for example, susceptibility is defined on the basis of crop types and plant phenology or types of life stock (Stöckle et al., 2003; Horridge, Madden, and Wittwer, 2005).

Currently, methods to assess direct economic losses due to coastal flooding in Europe are the same as those applied for riverine flooding (Kok et al., 2005; Penning-Rowsell et al., 2005; Vanneuville et al., 2006). A few take the special characteristics of coastal flooding into account, such as the Federal Emergency Management Agency (FEMA) (2011) and Nadal et al. (2010). Hardly any special damage models are available for Alpine floods, with the exception of ECONOME2.0, which distinguishes between static and dynamic floods (Kimmerle, 2002; Romang, 2004; BAFU, 2010).

Uncertainties of Damage Assessments

There are several reasons for the uncertainties associated with damage assessments. The most salient is the lack of reliable, consistent, comparable, and publicly available damage data (Mileti, 1999; Dilley et al., 2005; Greenberg, Lahr, and Mantell, 2007). This has been identified as a major obstacle to developing reliable damage models (Merz et al., 2010). Additional uncertainties arise from the need to transfer existing damage models (a) between elements at risk, (b) in time, (c) in space, and (d) between hazards (Merz et al., 2010).

The quality of existing damage models can be evaluated by performing model validations (Seifert et al., 2010; Penning-Rowsell and Green, 2000). Model validations usually assess whether a model produces similar results to observed damage in a given area for a certain event and whether it is suitable for predicting unobserved situations (Merz et al., 2010). Model validations can also be used to assess whether the model's performance could be improved by considering additional parameters (Elmer et al., 2010).

Data Sources

Developing and validating damage models requires predominantly object-specific data, since these provide insight into the damaging processes. However, most databases are event-specific; object-specific databases are rare.

For flood damage, probably the best known example of a synthetically generated database is that of the Flood Hazard Research Centre at Middlesex University, UK. HOWAS 21, the flood damage database for Germany (http://nadine.helmholtz-eos.de/HOWAS21.html), collects object-specific flood damage data from affected private households, commerce and industry, traffic areas and roads, watercourses and hydraulic structures (Thieken, Seifert, and Merz, 2010). HOWAS 21 is designed to contain empirical and synthetic loss data, but to date contains only empirical data (Buck and Merkel 1999; Merz et al. 2004).

Most of the existing damage databases are event-specific and contain aggregated damage figures. An overview of event specific databases for natural hazards on global, regional, or national scale is provided by Tschoegl et al. (2006) and UNDP (2013).

Assessment of Approaches: Cross-hazard Comparison

Approaches for the assessment of direct damage and production losses are qualitatively analyzed in tables 1 and 2.

1. Scope and purpose: This criterion regards the comprehensiveness of the method in the decision making system and examines if the method deals with certain types of costs or if it provides a comprehensive approach (gradation: sectoral, comprehensive)

2. Spatial scale: The spatial implementation dimension of the methods is analyzed under this criterion (gradation: local, regional, national, global)

3. Time scale: The time scale is analyzed concerning the time period that each method is covering when applied (gradation: short-term (on the spot up to several months), mid-term (approximately one year), long term (more than one year))

4. Data availability: This criterion concerns the availability of the data necessary for the application of each cost-assessment method (gradation: low, moderate, high).

5. Data quality: This criterion concerns the quality assurance of the data necessary for the application of each cost-assessment method (gradation: low, moderate, high).

6. Effort required: The financial and the human resources that are demanded for the application of each method are compared under this criterion (gradation: low, moderate, high).

7. Expected precision: It describes the precision of the results produced (gradation: low, moderate, high).

8. Scientific or practice approach: This criterion illustrates the development and application context of the approaches by classifying them into the scientific or the practical fields (gradation: scientific, scientific and practical, practical).

9. Skills required: This criterion refers to the knowledge skills required for the application of the methods (gradation: desk research, econometrics/statistics, modelling)

10. Ability to deal with the dynamics of risk. This criterion refers to the ability of the methods to deal with the dynamics of risks and to be implemented in future risk scenarios, mainly linked to climate change (gradation: low, moderate, high).

11. Implemented ex-ante or ex-post: It deals with the ability of the methods to be applied ex ante in a hypothetical or laboratory setting or ex-post based on market observations (gradation: ex-ante, ex post, ex-ante and ex-post).

12. Application. Describes, to what extent the respective method is applied by the four hazard communities (gradation: + = frequently applied, o = partially applied, - = rarely / not applied)

13. Example: Provides a reference to a study that applied the respective approach

Table 1. Cross-hazard Comparison: Direct Damage

	Scope	Spatial scale	Time scale	Data availability	Data quality	Effort required	Expected precision	Scientific or practice approach	Skills required	Ability to deal with dynamics of risk	Implemented ex ante or ex post	Application				Example
												Floods	Droughts	Coastal	Alpine	
Susceptibility function (based on a single-hazard parameter)																
Empirical (absolute / relative)	Sectoral / compre-hensive	Local to national	Short term	Low / moderate	Low / moderate	Low / medium	Low / moderate	Scientific / Practical	Statistics / modelling	High	Ex post / ex ante	+	o	o	+	ICPR, 2001
Synthetic (absolute / relative)	Sectoral / compre-hensive	Local to global	Short term	Low / moderate	Low / moderate	Low / medium	Low / moderate	Scientific / Practical	Statistics / modelling	High	Ex post / ex ante	+	-	o	-	Klijn et al., 2007
Multiparameter models (based on several-hazard impact and / or resistance parameters)																
Empirical (absolute / relative)	Sectoral	Local / regional	Short term	Low	Low / moderate	Medium / high	Moderate / high	Scientific	Statistics / modelling	High	Ex post / ex ante	o	-	-	o	Elmer et al., 2010
Synthetic (absolute / relative)	Sectoral	Local / regional	Short term	Low	Low / moderate	Medium / high	Moderate / high	Scientific	Statistics / modelling	High	Ex post / ex ante	o	-	o	-	Penning-Rowsell et al., 2005

Reported cost figures																
Self- / Media reports	Sectoral / Compre-hensive	Local to global	Short term / long term	Moderate	Low / moderate	Low	Moderate	Practical	Desk research	n.a.	Ex post	o	+	o	o	Martin-Ortega and Markandya, 2009
Comparison approaches																
Comparison hazard / non-hazard time periods	Sectoral	Local / national	Short term /medium term	Moderate	Low / moderate	Low / moderate	Moderate	Practical / scientific	Desk research	n.a.	Ex post	-	o	-	o	Benson and Clay, 1998
Integrated assessment models																
Agro-economic models	Sectoral	Local / regional	Short term / long term	Low / moderate	Low / moderate	High	Moderate	Scientific	Modelling / statistics	High	Ex post / ex ante	-	o	-	-	Holden and Shiferaw, 2004

n.a. = not available

Several conclusions can be drawn from the cross-hazard comparison provided in Table 1. Although the literature on assessing direct damage of flooding is comparatively extensive, the available damage estimation methods are far from satisfactory. Complex damaging processes are still commonly described by simple models, model validations are scarce, and associated uncertainties are hardly known and thus not communicated. Advances in flood damage assessment could trigger subsequent methodological improvements in other natural hazard areas with comparable time-space properties, such as coastal storms or certain Alpine hazards. More hazard-specific impact and resistance parameters should be integrated in damage modelling for flooding as well as for other hazard types.

Table 1 also shows that synthetic damage functions based on "what if" analysis have been primarily developed for flood damage assessments. Given the limited empirical basis of the object-specific damage data needed for empirical damage models, the application of synthetic damage functions or combined empirical-synthetic approaches could be a promising option for other hazard types.

Drought damage assessments differ from the other three risk types and are mainly applied ex post using cost figures of media or self-studies from interest groups and governmental authorities. Another approach are comparisons between drought and nondrought periods. Ex ante models for drought damage should be developed to enable drought risk assessments and the evaluation of drought damage mitigation strategies.

Table 1 also shows that most of the available damage models focus on certain sectors. Comprehensive damage models that provide a complete picture of damage from natural hazards are rare. To arrive at more comprehensive damage assessments, several sector-specific and hazard-specific damage models should be integrated under a common modelling framework, such as the Hazus model family of FEMA in the United States.

Table 2 shows that production losses are most often assessed for floods, and that assessments tend to use simple models that are not validated and that include unknown uncertainties.

Detailed assessment approaches of production losses due to various hazards could provide more accurate cost figures. These would be useful, given that ex post approaches currently applied for some hazards (for example, comparisons between drought and non-drought years) do not distinguish between direct damage, production losses, or indirect damage and are unable to deal with the dynamics of risk.

Table 2. Cross-hazard Comparison: Losses Due to Disruption of Production Processes

	Scope	Spatial scale	Time scale	Data availability	Data quality	Effort required	Expected precision	Scientific or practice approach	Skills required	Ability to deal with dynamics of risk	Implemented ex ante or ex post	Application				Example
												Floods	Droughts	Coastal	Alpine	
Assessment of losses to economic flows																
Based on damage data	Sectoral	Local / regional	Short term	Low	Low / moderate	Moderate	Low / moderate	Scientific / practical	Statistics / modelling	High	Ex post / ex ante	o	-	o	-	Parker, Green, and Thompson, 1987
Based on statistical data	Sectoral	Local / regional	Short term	Moderate / high	Moderate / high	Moderate	moderate	Scientific / practical	Desk research	High	Ex post / ex ante	o	-	o	-	FEMA, 2011
Percentage of direct damage																
Empirical	Sectoral	Regional	Short term	Moderate	Low / moderate	Low	Low / moderate	Practical	Desk research	High	Ex ante / Ex post	o	-	-	-	NRE, 2000
Synthetic	Sectoral	Regional	Short term	Moderate	Low / moderate	Low	Low / moderate	Practical	Desk research	High	Ex ante / Ex post	o	-	-	-	NR&M, 2007
Comparison approaches																

Comparison hazard / non-hazard time periods	Sectoral	Local / regional	Short term / medium term	Moderate / high	Low / moderate	Low / moderate	Low / moderate	Low / moderate	Desk research	Moderate	Ex post	-	o	-	o	SLF, 2000
Reported cost figures																
Self / Media reports	Sectoral / compre-hensive	Local to global	Short term / long term	Moderate	Low / moderate	Low	Low / moderate	Practical	Desk research	n.a.	Ex post	-	+	-	-	Martin-Ortega and Markandya, 2009

n.a. = not available

Recommendations

Below, we highlight remaining knowledge gaps and make recommendations—some overarching, some hazard-specific—based on them.

Overarching Recommendations

1. Develop a consistent framework for direct cost assessments to make them comparable.

Current methods for assessing direct damage from natural hazards exhibit considerable heterogeneity. The lack of a common assessment framework hampers the comparability of cost estimations.

Recommendation: A consistent framework should be developed to facilitate collection, analysis, modelling, and comparison of costs of various natural hazards in the European Union.

2. Improve data availability and quality.

The lack of reliable, consistent, and publicly available damage data is a major obstacle to understanding damage processes, and thus to developing, improving, and validating methods for direct cost assessment across all hazard types. Existing data focus on hazard characteristics more than on associated damage and damage processes, and few databases collect object-specific damage data. Because data are collected by different organizations applying different standards, they tend to be heterogeneous, and are often of low quality and not validated. Most exposure data (such as economic assets at risk) are available only at an aggregated level, which often leads to a spatial mismatch between hazard and exposure data.

Recommendation: Empirical and synthetic object-specific damage data collection must be improved in order to provide homogenous and reliable data. More object-specific data, including a broad range of potentially damage-influencing parameters, need to be collected in order to improve existing cost assessment methods and develop new ones. A minimum standard for object-specific damage data collection should be established for European databases.

3. Address uncertainty in direct cost assessments.

Most cost assessment methods describe complex damaging processes by means of rather simple susceptibility functions, which are often based on a single hazard parameter (such as depth-damage functions in the case of floods). Current models also tend not to reflect a range of damage-influencing hazards and resistance parameters (such as mitigation measures). These weaknesses result in the uncertainties commonly observed in cost assessments.

Recommendation: Multifactor damage models that better capture the variety of damage-influencing factors should be developed. These models should integrate resistance parameters, which make it possible to evaluate and compare various structural and nonstructural risk mitigation strategies.

4. Validate models.

Existing damage models are hardly validated—even though validation makes determining the accuracy of cost assessments possible. Many damage models are currently transferred in space and time—that is, from region to region or from one event to the other—even where their applicability has not been established.

Recommendation: To produce sound and useful models for Europe, and to make clear where transferring models in time or space is appropriate, greater effort should be made to validate the results of existing damage assessment methods.

5. Improve completeness of direct cost assessments.

Sector-specific approaches to assessing direct damage from natural disasters provide an incomplete picture of potential direct damage from natural hazards. All economic sectors—including industry and commerce—contribute significantly to overall losses, but relatively few damage models examine damage in these sectors.

Recommendation: Cost assessment methods could reflect a greater spectrum of direct losses caused by natural hazards. Methods should consider a broader range of economic sectors, including industry, commerce, and infrastructure. Several sector- and hazard-specific damage models should be integrated under a common modelling framework, such as the Hazus model family of FEMA in the United States.

6. Consider losses due to the disruption of production processes.

Losses arising from the disruption of production processes are often neglected, even though they may significantly contribute to overall damage, especially for large-scale events.

Recommendation: Especially for large-scale natural hazards, more attention should be paid to the assessment of losses caused by the disruption of production processes. Cost estimates of production losses should be based on detailed assessments of losses to economic flows within the hazard zone.

7. Develop integrated damage assessment methods.

Few integrated damage-assessment methods take the effect of coupled and coinciding natural hazards into account.

Recommendation: Work should be intensified towards the development of integrated damage-assessment methods that reflect the interplay of possible coinciding natural hazards.

Hazard-Specific Recommendations

1. For flood risk, emphasize classifying and quantifying asset values, examining the damage-reducing effects of flood risk mitigation measures, and developing socio-economic scenarios.

Compared to flood hazard modelling, detail and resolution of asset assessments are coarse; this discrepancy often creates a spatial mismatch between flood hazard and exposure data. While it is increasingly acknowledged that technical flood protection needs to be accompanied by protection measures on the level of individual buildings and businesses, the damage-reducing effect of such measures is still largely unknown. Finally, while information on socio-economic variables is important for realistically assessing flood risk over time, current scenarios are limited by their use of only very large-scale information (such as changes in gross domestic product, population, or land use).

Recommendations: More attention should be given to classifying and disaggregating asset values. More sophisticated methods (for example, multivariate analyses and data mining) should be used in examining the damage-reducing effects of flood mitigation measures for different flood types. Expanded socioeconomic scenarios should be developed including more detailed variables needed for more realistically assessing future flood damage.

2. For droughts, improve certainty in and relevance of damage estimations.

Most studies of direct costs of drought are ex post analyses, based on self-studies and media studies, and focus on the agricultural sector . They are therefore prone to biases and uncertainties, and they do not address the structural damage to buildings and infrastructure caused by drought-induced soil subsidence. Studies that assess drought damage by comparing production output during drought years with production output during nondrought years also imply considerable uncertainty, since causes other than drought may lead to a decline in production. Finally, because drought damage models fail to take drought mitigation measures into account, the damage-reducing effect of drought mitigation measures is largely unknown.

Recommendations: Ex ante models should be developed, so thatdrought damage over time can be examined and various drought damage mitigation strategies evaluated. Future research should also focus on structural drought damage assessments. Drought damage models based on assessments of losses to economic flows should also be developed; these could significantly improve current cost assessments

3. For coastal hazards, develop hazard-specific damage functions.

Current methods for assessing direct costs of coastal hazards lack specific damage functions. Instead, damage functions that were derived and constructed for assessing riverine flooding are commonly applied to potential damage from coastal flooding.

Recommendation: Specific damage functions should be derived and applied for the assessment of coastal flooding. Future research could seek to determine to what extent damage functions for riverine flooding can be transferred to coastal areas. In line with the recommendation provided by FEMA for the United States, standard depth damage functions should not be applied if high-flow velocities and wave forces can be expected.

4. For alpine hazards, take cascading hazards and hazard-specific characteristics into account.

Alpine hazards are associated with a risk of cascading and coinciding natural hazards that can show a range of different damaging processes, but no current methods address this fact. Moreover, the characteristics of mountain floods differ from those of other floods, and these are not captured by standard depth-damage functions.

Recommendation: Work toward integrative damage assessments methods that capture potentially coinciding events. In line with the FEMAS's recommendation for the United States, do not apply standard depth damage functions if high-flow velocities, ice- or debris-induced damage, or erosion is expected.

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