

Understanding trends and projections of disaster losses and climate change: is vulnerability the missing link?

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Abstract The recent IPCC-SREX report demonstrated for the first time comprehensively that anthropogenic climate change is modifying weather and climate extremes. The report also documents, what has been long known, that losses from natural disasters, including those linked to weather, have increased strongly over the last decades. Responding to the debate regarding a contribution of anthropogenic climate change to the increased burden from weather-related disasters, the IPCC-SREX finds that such a link cannot be made today, and identifies the key driver behind increases in losses as exposure changes in terms of rising population and capital at risk. Yet, in the presence of many uncertainties and omissions involved in studying trends in losses, the authors of the IPCC report did not exclude a role for climate change. In particular, one key uncertainty identified has been the incomplete consideration of economic vulnerability to natural hazards, defined as the propensity to incur losses in a hazardous event. Focussing on the role of vulnerability in determining today's and future disaster loss risk, we critically review the literature on loss trends and projections, and provide context by way of a modeling case study of observed and projected losses from riverine flooding in Bangladesh. We find that research has almost exclusively focused on normalizing losses for changes in exposure, yet not for vulnerability, which appears a major gap given the dynamic nature of vulnerability, and documented evidence regarding decreases in vulnerability in many regions. One such region is South Asia, and of particular interest to us is Bangladesh, a country heavily at-risk, but also with substantial expertise regarding risk management, where we are able to show that economic vulnerability has been substantially reduced over the last decades. In order to understand future flood risk in Bangladesh, we project risk based on past reductions in vulnerability and compare it to a case where vulnerability is not considered explicitly and kept static. In the dynamic scenario, risk would

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still increase in absolute terms, yet at much smaller increments compared to a static vulnerability case. Thus, a key finding of our analysis is that, absent dynamic quantifications of vulnerability, studies on future losses under climatic change may overestimate future losses. Furthermore, the analysis also suggests that there are substantial benefits to gain by supporting vulnerability-reducing measures in many regions. Finally, we emphasize the need for further taking a risk-based perspective on modelling climate impacts in order to provide robust information on the costs and impacts from extremes in a changing climate.

1 Climate change and unnatural disasters

Much of the concern about climate change has to do with projected shifts in the occurrence of events linked to weather and climatic extremes such as floods and droughts. Managing climate-related disaster risk is considered a priority area for action on climate adaptation, and features prominently in many studies, reports and public attention (UNISDR 2009). The recent IPCC special report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (IPCC 2012) was the first comprehensive review that brought together scientific knowledge from the climate and disaster communities. This report documents that many, as the report suggests, climate extremes are already changing in intensity, duration and frequency, and that part of these changes are induced by anthropogenic climate change. Recently, IPCC (2013) corroborated this message. A second very different anthropogenic intervention that makes disasters unnatural, as also laid out in the IPCC-SREX, is the fact that natural hazards become disasters only through the mediating determinants of exposure and vulnerability. Both of these unnatural components are important, are often mixed up and not examined independently.

Economic losses from weather extremes are particularly in the spotlight. Over the last decades, losses from natural disasters including those from events related to extreme weather have strongly increased. This has given rise to suggestions that anthropogenic climate change has been adding to the loss burden. Heavy and contentious debate has ensued and is ongoing (see Pielke and Sarewitz 2005; Pielke et al. 2005; Bouwer et al. 2007; Nicholls 2011; Bouwer 2011a, b; Bouwer and Botzen 2011; Huggel et al. 2013). Yet, although physical science evidence indicates that some extremes have indeed changed concurrent with anthropogenic climate change, as of today, this has not been shown for the losses. In fact, the IPCC-SREX finds exposure of people and capital at risk the dominant cause behind any increases in losses (Handmer et al. 2012). This is only half of the story, however, and there are a number of uncertainties involved in studying trends in losses, projections and the attribution to climate change. One research gap has been the incomplete consideration of economic vulnerability, defined by the disaster community as the predisposition to incur losses. Given the caveats, the IPCC-SREX also concludes that “a role for climate change has not been excluded” (IPCC 2012).

Yet, how important is economic vulnerability for loss trends and projections, and what empirical and modeling evidence can be brought forward? Presenting the basis behind the IPCC statements, and discussing key uncertainties and gaps in the literature, we identify vulnerability as an important driver of disaster risk, which has not been studied sufficiently in the context of climate change. It has been found to be decreasing in a number of regions, which may have masked changes in risks imposed by other drivers including climate change. Informed by an example of vulnerability and risk of flooding, often considered the key climate-related natural hazard, and examining the case of Bangladesh, we study the implications of explicitly accounting for vulnerability as a key component of risk. Bangladesh is an interesting case in point as it is considered a disaster and climate hotspot, and at the same time

significant efforts have focused on reducing vulnerability over the years. We find economic vulnerability an important component of flood risk and suggest that, absent explicit quantifications of vulnerability, studies on future losses under climatic change may overestimate future risk in Bangladesh and elsewhere. In order to work towards more robust projections of future risk we suggest more effort needs to be extended to better understand this factor in combination with the other main risk drivers of hazard (incl. climatic change) and exposure.

Our discussion continues with methodological remarks in section 2, which lead into a global review of weather-related disaster loss trend analyses, projections and their key drivers including vulnerability in section 3. In section 4, we provide context on vulnerability and risk quantification by way of a case study on riverine flooding in Bangladesh. This section also provides projections of flood risk in Bangladesh explicitly accounting for vulnerability, which leads into the conclusions.

2 Risk and risk analysis: definitions and methodological remarks

Key methodological elements of our analysis are a comprehensive review of global loss trend and projection studies, as well as one exemplary risk modeling application to the case of riverine flood risk in Bangladesh. The discussion and methodology is organized around the science and practice of disaster risk analysis and catastrophe modeling. We shortly present concepts of relevance as well as a discussion of the costs associated with extreme events.

2.1 Risk analysis in a changing climate

The entry point to our discussion is to understand disaster risk as a dynamic function of natural hazard, vulnerability and exposure. This is essential for understanding how unnatural disaster risk is in terms of being determined by socio-economic factors (exposure and vulnerability) as well as the role of climate change in modifying natural hazards. Another important aspect for the analysis of extreme events is a need to represent risk in stochastic terms and derive probabilities associated with losses for entire stochastic distributions (generally called loss-exceedance distributions). The need for risk-based analysis, and particularly looking into the tails of distribution has to do with the fact that a key principle employed in the disaster risk community is that of risk layering, which means instruments are differentially applicable and effective depending on the return period of events (see Linnerooth-Bayer and Hochrainer, this issue). Instead of the tails, however, for simplification reasons, often annual average (expected) losses are used as a proxy, which does not pay full tribute to the nature of extremes.

Vulnerability has been a key concept for studying impacts from hydrometeorological (as well as geophysical) variability as well as climate change. Definitions have been subject to substantial research and debate over the years (Burton et al. 1978; Adger et al. 2005; Füssel and Klein 2006; Hinkel 2011; Birkmann 2013). In disaster risk analysis, vulnerability is considered the degree of damage or (when monetized, loss) in a natural event (e.g., losses associated with certain levels of flood depth or extent) (see Birkmann 2013). The climate community has traditionally focused on the climate increment, and vulnerability has been considered a function of sensitivity and adaptive capacity to climate change (IPCC, 2012). Departing from the definitions used in earlier IPCC reports, the IPCC-SREX report adopts the (older) definition used in natural disaster risk analysis, which is defined as "... the propensity or predisposition to be adversely affected" (Lavell et al. 2012). A point worth mentioning is that vulnerability in the IPCC tradition has often been considered an endpoint of the analysis (measured by using indicators and indexes) for identifying vulnerable actors and sectors, while risk until recently

has not been a major consideration in analyses of climate impacts; on the other hand, disaster risk analysts generally strive to quantify vulnerability as an input to estimating and eventually managing risk. To this end, vulnerability functions indicating the degree of damage or loss for different levels of hazard intensity (also called stage-damage curves) can be employed. As accepted for this analysis also, vulnerability is finally linked to hazard (likelihood and severity of weather and climate events) and exposure (economic capital) to arrive at an estimate of risk of loss (Grossi and Kunreuther 2005; Amendola et al. 2013).

2.2 Costs and losses from extremes

Disasters are events in which widespread adverse human, material, economic, or environmental effects result from hazardous events (IPCC 2012). In a climate change context, costs associated with disasters fall into three categories: damage costs or losses, adaptation costs, and the residual costs, which can be considered the net losses after adaptation. Although conceptually, the different cost categories are linked, in practice they have rarely been studied in unison (see Handmer et al. 2012). This is unsurprising, as researchers involved in studying the costs from extremes hail from different scientific disciplines and, at least, two different communities (disaster risk management, climate adaptation); finally there are major methodological and data issues, which require special attention and are discussed in the following (see also Agrawala et al. 2011).

Losses are usually grouped into three categories (direct, indirect, and macroeconomic) and two types (asset or flow impacts). Direct economic losses – the focus of this article – are mostly the immediate destruction of assets, which then lead to indirect, sectoral flow effects on goods and services affecting households and firms, as well as macroeconomic effects on the aggregate economy (ECLAC 2003). When utilizing loss data information, it is important to keep in mind that observations of loss data on extreme weather events cannot be regarded to be of the same quality and homogeneity as other data used for so-called detection and attribution studies that are often applied to observed records of biophysical changes (see e.g. Rosenzweig et al. 2008). Uncertainties are high, and reports from different sources have exhibited large differences for the same events (see e.g., Gall et al. 2009). Longer records of economic losses from natural hazards have been collected for research and business (mostly insurance and reinsurance) purposes, but only few institutions have done so in systematic fashion, one being the EMDAT database, which we build on (CRED 2013). While larger events appear well covered, there is a known bias of under-reporting for smaller loss events dating earlier than the 1980s (UNISDR 2011). Loss estimates are generally limited to include all direct monetized physical damage to assets, but not business interruption and non-market losses such as health and cultural impacts and environmental damages. There are only a few studies on dynamic changes in non-market losses, such as loss of life (Jonkman 2005).

3 Disaster loss trends and projections

Various sources exhibit that disaster event occurrence and losses have increased over recent decades. As one example, the number of weather-related loss events, dominated by river flood and windstorm events, has increased more rapidly than geophysical events, that include earthquakes and volcanic eruptions (Handmer et al. 2012). It is important to note that this deviation of weather-related events relative to non-weather must not be interpreted as proof that there is a change in weather hazards; one can only conclude that loss events have increased for weather-related hazards, which may also be induced by changes in exposure and vulnerability, that can differ for weather and

non-weather hazard types (Bouwer 2011a). For example, population exposure increases in concentrated areas may be higher for particular hazard types, which has been especially apparent for floods, storms and landslides (Kellenberg and Mobarak 2011; Bouwer 2011a).

3.1 Trends in losses

Several studies have looked at trends in overall global losses from extreme weather. While, in general, all studies agree that losses have increased over time with large inter-annual variability (see also IPCC 2012), there are different interpretations as to whether this trend is monotonic or not. Studies from Munich Re (e.g., Munich Re 2011) suggest that losses have steadily increased over time with some years with lower losses. A recent study however insists that since the 1990s growth in losses has stalled (Visser and Petersen 2012) While Munich Re suggests that there is a positive trend to increasing losses, Visser and Petersen (2012) suggest such trend estimation is not robust and a trend disappears when adopting their model (see figure SF1). This latter study, while not considering losses in 2011- the year with the largest-ever losses (Munich Re 2012), does show that loss trends are heavily dependent on choices regarding statistical models. While Munich Re and others have used an exponential trend type model, Visser&Petersen (2012) use an integrated random walk set-up, and both choices appear defensible. In any case, a substantial increase in the number of loss events and risk of economic loss over recent decades has been observed; whether this continues will need to be seen. The next section will address possible causes of this observed increase; later we will discuss projection studies that generally suggest increasing risk as well.

3.2 Causes of increases in losses

A number of studies published over the last few years have investigated time series of losses from weather extremes in order to understand past increases and causes thereof (see table ST1 for key studies). These studies have used a so-called normalization approach, which means they correct observed losses by applying an index or several indices for exposure (Pielke and Landsea 1999). This index is usually based on per capita wealth, expressed by building or content value, or using GDP as a proxy (Bouwer 2011a). Signals of climate variability can be recognized in the data, for instance, for hurricane losses that vary over time with ENSO (Pielke and Landsea 1999). Most studies show that after adjusting for socioeconomic factors, no trend is apparent. The IPCC-SREX concluded, on the basis of the studies available (most of the studies listed in Table 1), that the main cause for the long-term increase of losses from weather and climate extremes has been increasing exposure of people and assets (IPCC 2012). This statement, concluded with high confidence, is based on various national and local case studies available for specific hazards (e.g. Pielke et al. 2008; Bouwer et al. 2007; Bouwer 2011a) and for different regions, using a range of different normalization types (high evidence), and consistent findings (high agreement). Overall, the IPCC-SREX reports that observed trends after adjustment for non-climatic influences have not been attributed to climate change. New papers published since the IPCC-SREX report also reconfirm this (see papers highlighted in bold in table ST 1).

Yet, the report also identifies a number of important caveats and did not rule out that climatic change may be having an impact on losses (Handmer et al. 2012). Among the issues mentioned are a focus on a few hazards only (mainly riverine floods, and tropical cyclones) and limited data on losses and crucial loss components such as exposure and vulnerability. Many studies have used loss databases with a limited length (periods shorter than 40–50 years), which reduces the possibility to determine impacts of anthropogenic climate change. Very importantly, most studies have not accounted for changes in vulnerability to weather extremes. Some studies have

suggested that, while exposure has increased, vulnerability may have automatically declined as countries get richer and invest in early warning, protection and risk reduction (UNISDR 2011; Kellenberg and Mobarak 2011). There is very little information and evidence regarding the role of vulnerability for loss trends. Only two studies conducted for a climate adaptation context (Tanner et al. 2007; Crompton and McAneney 2008) dynamically account for reductions in vulnerability due to improvements in building codes and reduced economic vulnerability. Outside of a pure climate change focus, UNISDR (2011) and UNESCAP (2012), in order to understand how disaster risk is shaped by its components over time, report regional trends for exposure, vulnerability and risk, based on observed losses, vulnerability and exposure. With hazard considered unchanged vulnerability has been found to reduce over time for a number of regions and hazards. However, the effect of decreases in vulnerability coupled with increases in exposure on risk varies across regions (see Figures SF 2 and 3).

Overall, given these gaps and challenges, the IPCC-SREX did not exclude a role for climate change, and it has been suggested that, the effect of not accounting for vulnerability, if sufficiently large, may mask changes imposed by anthropogenic climate change on extreme events' duration, frequency and intensity as also discussed recently by (Nicholls 2011; Nicholls and Seneviratne 2013).

3.3 Projecting losses

Projecting loss trends in the future (mostly up to 2,050) has been the topic of a series of studies. While most projection studies have been devoted to changes in hazard, a series of studies has also translated these changes into potential economic losses, using loss functions or loss models. Moreover, a few studies have also taken into account other drivers that influence exposure, in particular socioeconomic development (for an overview, see Bouwer 2013).

Available studies generally project increases for losses resulting from tropical cyclones, extra-tropical cyclones and river floods (Fig. 1), as a result of anthropogenic climate change.

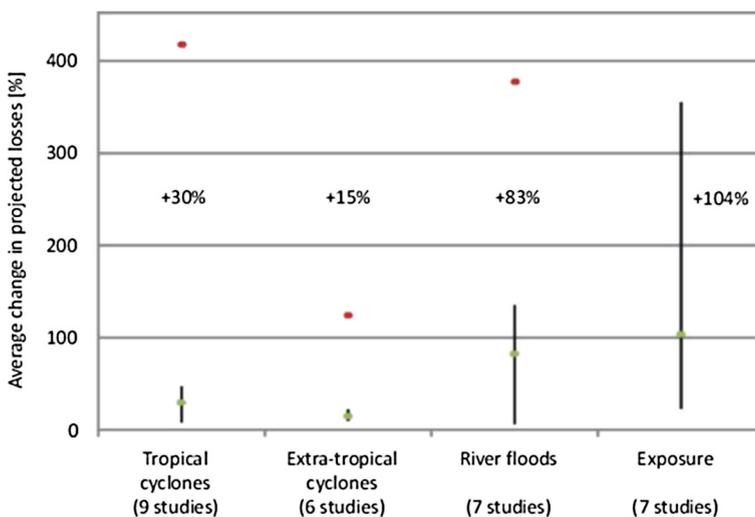


Fig. 1 Projected changes in losses for key hazards and exposure by the year 2040 in response to anthropogenic climate change. Bars: ranges of the average estimates of the different studies; green dots: median for different hazard types; orange dots: outliers. Projected changes from exposure are indicated for comparison (based on Bouwer 2013)

The ranges of projections are due to differences in location, assumptions and scenarios about projected changes in climate and related weather extremes, and a relation between hazard and loss. The properties of these studies vary, but generally follow an impact assessment approach, considering changes in hazard as well as exposure, leading to changes in losses compared to a certain baseline (these properties are described in detail in Bouwer (2013)). Importantly, the effect of projected increasing exposure of assets, in response to on-going socioeconomic development, is generally considered to be larger than changes in risk resulting from projected anthropogenic climate change (Handmer et al. 2012; Bouwer 2013). Based on this information, IPCC (2012) concluded that “in many regions, the main drivers of future increases in economic losses due to some climate extremes will be socioeconomic in nature (medium confidence, based on medium agreement, limited evidence).”

Similar to the lack of accounting for vulnerability in trend assessments, absent a good evidence base, vulnerability has not been projected forward by the studies reported above. The Bangladesh case of flood risk discussed in the following (based on Tanner et al. 2007) is one (of two) exceptions in the literature and interesting in its own right as it provides evidence on the significant contribution of vulnerability reduction to changes in risk.

4 Understanding and modelling vulnerability and risk: the case of flood risk in Bangladesh

Vulnerability has not truly been considered in trend analyses and projections of losses under climate change; yet how important is this driver of risk of losses? We suggest it is a key component for understanding and better managing risk. We illustrate this in the following via an exemplary numerical risk modeling exercise for economic vulnerability and risk associated with flooding in Bangladesh, one of the most flood prone countries in the world and at the same time a leader in proactive disaster risk management.

In order to better understand what disaster risk and vulnerability mean today and the future, it is insightful to look at specific country-level risk, losses and return periods, thus giving proper credit to the low-frequency/high-impact nature of disasters. Detailed data is, however, generally and by definition scarce for extremes, and associated with substantial uncertainties. Bangladesh is a case for which rather good and comparable data is available, which allowed for a sufficiently broad-based analysis.

4.1 Observing vulnerability to riverine flooding in Bangladesh

The analysis builds on research conducted to understand the relevance of disaster risk and appropriate interventions for climate adaptation and climate proofing in Bangladesh for today and time periods up to 2020 and 2,050 (see Tanner et al. 2007; see SM4). Among others, the research calculated future flood risk based on observed flood intensity (area flooded), vulnerability and a climate signal on flood intensity. Comprehensive data were available in probabilistic format with return periods for recorded impacts of the largest riverine flooding in Bangladesh over the last 40 years including area flooded, exposed population and economic capital, fatalities, damage to housing as well as monetary losses (see ST1).

As commented, various types of vulnerability exist and all of them, including their complex interdependencies, are important for determining the consequences of an extreme natural hazard event. We focus on two types, social (loss of life) and economic (economic losses) vulnerability. The modelling element to be highlighted here is economic vulnerability to flooding, which is

defined as the susceptibility to incur losses and operationalized in terms of a stage-damage curve of losses per area flooded. While, often, losses are calculated as a function of flood depths, for this large-scale national assessment, flooded area is used as a proxy for flood intensity, which has been used in other studies, particularly in Bangladesh as well (see SF 4 and ST 3).

Three steps were performed to develop an economic vulnerability function, which then can be used to project vulnerability (and risk) forward): (i) normalizing impacts, (ii) relating normalized risk to a measure of hazard, and (iii) identifying a time trend. The normalizations in line with the discussion above consisted in relating manifested risk in terms of observed economic losses to overall economic exposure, taken as GDP in constant terms. While technically, it would be more correct to relate losses to economic assets- machinery, structures, infrastructure- such a transformation can be achieved with a simple production function, and would not add more to the discussion, yet complicate the analysis as climate scenarios project GDP, not assets. Applying such normalization, including loss of life per area flooded for purposes of comparison, Fig. 2a exhibits how indices of such constructions of vulnerability have decreased dynamically over time.

We find economic vulnerability and vulnerability of loss of life strongly decreasing in Bangladesh (see Fig. 2a), of which the reductions in vulnerability of loss of life are particularly striking. To provide context, comparable flooding in 1974 (with a return period of 9 years and land area affected of 53,000 square kilometers) and 2004 (return period of 11 years and land area flooded of 58,000 square kilometers) led to very different impacts. Loss of life in the 1974 flood was at close to 29,000 people, whereas in 2004 the death toll was two magnitudes lower at about 761 people indicating vulnerability of loss of life was reduced. While absolute losses in 2004 were larger due to economic expansion, the loss as a share of GDP was smaller at close to 3.3 % compared to 7.5 % in 1974 suggesting economic vulnerability had been decreased as well.

Many factors may explain the reduction in vulnerability, which can be related to autonomous or exogenous adaptive behavior (better risk awareness, building codes, increased incomes, etc.). As a case in point, Bangladesh, with external assistance, has over the last five decades invested about USD 10 billion into disaster risk management, such as cyclone and flood shelters, river embankments, drainage systems, and erosion control measures (see MOEF, 2005; World Bank 2010). Yet, as it is well understood, vulnerability is multifactorial, and as our research focus is on understanding the dynamic nature of vulnerability, and not identifying the various determinants of vulnerability, which would be a different analytical exercise, we proceed empirically: Based on empirically observed decreases, we project vulnerability forward using a dynamic vulnerability index (see SM4).

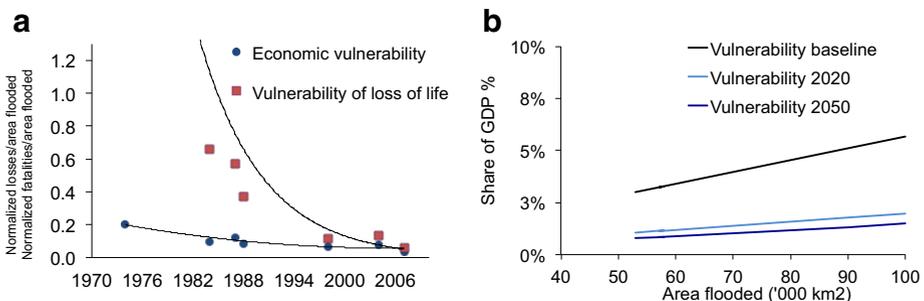


Fig. 2 a,b: Observed changes in economic vulnerability and vulnerability of loss of life (left panel), and derived economic vulnerability functions (right panel) for riverine flooding in Bangladesh. Source: Extended from Tanner et al. 2007

By using such an index, we simply consider vulnerability dynamic in order to study the effects on future risk (in a changing climate) if observed vulnerability reductions are maintained. We neither identify (the various hard and soft) vulnerability reducing factors, nor suggest it is reduced autonomously with increasing economic output. GDP growth and vulnerability reduction are in fact modeled separately and as a consequence future vulnerability reduction is independent of GDP projections, which are given exogenously. As a next step, when applying this index, we can adjust observed vulnerability in previous years to construct a stage-damage curve for today’s losses, and further derive time-dependent functions for 2020 and 2050 (Fig. 2b). As a consequence, losses per flood intensity will substantially reduce over time.

4.2 Projecting vulnerability and risk to riverine flooding in Bangladesh

As a next step, we now take the Bangladesh experiment further and link hazard, exposure and vulnerability to an estimate of risk, which we calculate for today, 2020 and 2050 including changes in climate. Analysis was only available for the B1 climate scenario as a worst-case scenario, which compared to the A1 scenario, has a stronger impact as it projects stronger GDP growth for Bangladesh leading to larger exposure of capital to flood hazard (See SM4). Combining vulnerability (as normalized GDP losses per area flooded) with exposure (taken exogenously) and hazard leads to an estimate of risk. Flood hazard, which due to the country-level approach taken is based on statistical analysis, and not hydrological modeling, is affected by climate change due to increases in precipitation and discharge, which leads to larger areas flooded and consequently increased losses. Figure 3 shows the exceedance-loss curves for the three time steps and two scenarios: one where vulnerability is dynamic in line with the prior discussion, and one where it is constant. Figure 3 shows losses as a share of assets overall (3a) as well as in absolute 2005 constant USD (3b).

By keeping vulnerability constant, we can gauge the importance of this factor in shaping risk. Absent a counteracting effect due to a reduction in vulnerability (Const V), risk will increase due to increases in exposure of assets as well as increased hazard in terms of inundation associated with stronger riverine flooding from heavier monsoon precipitation. The increase seems very large as compared to today’s risk baseline; for example, asset losses from a 20 year event would increase from 4.8 % to 5.8 % to 6.1 % of GDP in 2020 and 2050 respectively. In contrast, when modelling vulnerability as dynamic, losses in relative terms may decrease from 3.8 % to 1.6 %. In absolute terms, with exposure increases given by the climate scenario, losses would increase for both scenarios. For the dynamic vulnerability scenario, from 2.1 to 3.2 to 11.6 billion USD by 2020 and 2050 respectively, which is

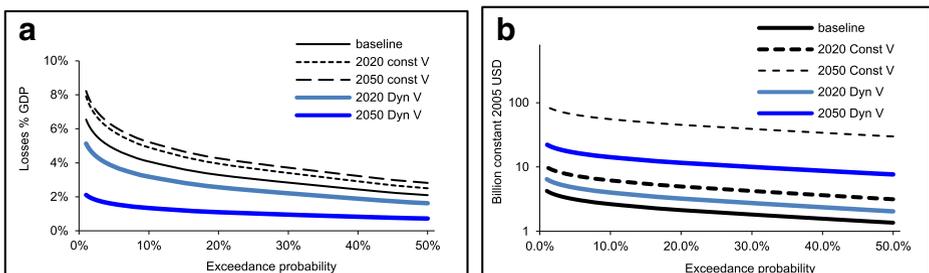


Fig. 3 a,b: Baseline and projected riverine flood risk in Bangladesh

significantly less compared to losses increasing to 4.0 and finally 45.2 respectively for 2020 and 2050 for the constant vulnerability assumption.

Uncertainties of this exemplary analysis are non-trivial due to the country-level approach taken as well as modelling choices including functional forms, data availability and regional projections of climate change as well as parameter uncertainties (see supplement). In terms of functional forms, those that gave the best fit or which were most suitable for extremes, i.e. distributions with fat tails (such as the Gumbel distribution), were chosen.

Finally, both scenarios are not likely to precisely project future risk. Yet, they outline the space of future losses based on pessimistic and optimistic parameter assumptions, and exhibit the important role vulnerability plays in shaping risk.

4.3 The regional and global perspective

How representative is the Bangladesh analysis in terms of the trends identified? When comparing results of the Bangladesh case to regionalized information produced by UNISDR (2011) for the South Asian region (which Bangladesh is part of), as well as to OECD countries (for a comparison with a different set of countries), we can see similarities and differences, albeit owing to data availability, of necessity for different time periods and hazards (for South Asia, comparable information was only available for tropical cyclones) (see Fig. 4). Economic vulnerability, reduced in Bangladesh, for the region has also been reducing, whereas the trend for OECD is essentially flat. Exposure for the two regions is similarly increasing, while this trend is strongest for Bangladesh. As presented, according to this analysis, while risk appears to have decreased in relative terms in Bangladesh, in absolute terms it has been increasing, whereas in the region the trendline has only recently started to slope downward. In contrast, in OECD countries, flood risk appears to essentially been rising. Trends are not fully monotonic for the Bangladesh case, which may be related to lack of consistently measuring impacts and losses as discussed in section 2.4.

5 Conclusions: The role of vulnerability for understanding trends in disaster risk

Losses from disasters, including weather-related events, have risen over recent decades, of which losses from flooding are a key concern. Concurrently, global warming is ongoing, which, as the IPCC-SREX lays out, modifies intensity, frequency and duration of climate extremes such as heatwaves, droughts and heavy rainfall. Consequently, many analysts, policy advisers and the public throughout are interested in understanding whether trends in losses can

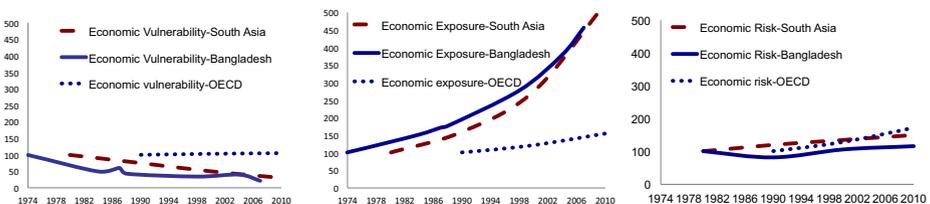


Fig. 4 Observed changes in economic vulnerability, exposure and risk for disaster risk in Bangladesh, South Asia, and the OECD (normalized to different years). Note: Hazard for Bangladesh and the OECD is flooding (marked in blue); for South Asia tropical cyclones (marked in red). Data sources: Tanner et al. 2007; UNISDR 2011

be attributed to climate change. This analysis has shown that this case cannot be made given the state of the art of the relevant research, and currently the key driver behind increases in losses has been found to be exposure (IPCC 2012). Yet, given the physical science' evidence pointing in the direction of a contribution of anthropogenic warming to increases in physical impacts from climate extremes, the case is clearly not closed.

Our global review on loss trends and projections suggests, that, although there is a growing body of research, there are salient issues associated with these estimates. Trend analyses have concentrated on normalizing losses for changes in exposure only. Projection studies have not considered and modeled vulnerability explicitly for assessing risk dynamically over longer time horizons.

This is, on the one hand, surprising, as vulnerability is the key focus of attention of disaster risk management and also more recently, climate adaptation. On the other hand, this line of research is emerging, and, as we have shown, there are serious challenges associated with data, aleatoric and modelling uncertainties. Data and aleatoric uncertainties in terms of gauging return periods and losses for extremes range high, also owing to a lack of comprehensive and reliable data on extreme events and their drivers. Further, modelling uncertainties and omissions play a large role as well, of which operationalizing vulnerability quantitatively is one. A key gap we examined here, is the lack of considering and quantifying agents' ability to reduce risk over time, which we consider as economic vulnerability, the predisposition to incur losses in a given hazardous event.

Focusing on an exemplary case of observed and future losses from riverine flooding in Bangladesh, a country extremely at-risk, yet at the same time also extremely experienced with managing risk, we provide reflection regarding the role of vulnerability for estimating risk. This case study with rather good data on risk drivers in probabilistic format (i.e., return periods representing aleatoric uncertainty) shows that vulnerability, both in terms of the predisposition to incur bodily harm as well as monetary loss, has indeed substantially declined over the last decades. Furthermore, when accounting for vulnerability reductions in projections of risk in terms of average annual losses over decades until 2050, it turns out that indeed vulnerability is a key driver to be considered. When only exposure and hazard (riverine flooding) are considered dynamic, projected risk will increase very strongly. The risk increment seems unrealistically large (and pessimistic), and much higher compared to the dynamic (more realistic, yet very optimistic) case, where we also consider changes in vulnerability based on past experience.

There are many uncertainties involved in these projections and we used a dynamic trend for vulnerability reduction, while our illustrative analysis did not aim at identifying key determinants of risk reduction and whether vulnerability is induced autonomously or exogenously by policies and interventions (both seem to play role). Yet, the example shows the importance of considering (economic) vulnerability explicitly in projections of future risk. Projections made on the basis of hazard and exposure change only may overestimate actual changes in future risk, but also underemphasize the efforts that can be made to reduce risk.

Overall, there are a number of open questions regarding the effect of socioeconomic and climatic change on climate extremes. The IPCC-SREX report marks the beginning of a more focused and systematic research process for identifying these contributions to risk and tackling the methodological challenges involved in working towards more robust estimates of future losses from climate extremes. As global donors and climate negotiators ponder pledging and distributing financial support for the Green Climate Fund and work out the exact functions of the Warsaw Loss&Damage mechanism, tackling these challenges will lead to novel insights

that may help to plan and prioritize support for building climate resilience by further bolstering vulnerability.

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