International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Interim Report **IR-09-030**

Assessing current and future impacts of climate-related extreme events. The case of Bangladesh.

Stefan Hochrainer (hochrain@iiasa.ac.at)
Reinhard Mechler (mechler@iiasa.ac.at)
Georg Pflug (pflug@iiasa.ac.at)

Approved by

Joanne Linnerooth Bayer
Leader, Risk and Vulnerability

October 01, 2009

Contents

Abstract

Extreme events and options for managing these risks are receiving increasing attention in research and policy. In order to cost these extremes, a standard approach is to use Integrated Assessment Models with global or regional resolution and represent risk using add-on damage functions that are based on observed impacts and contingent on gradual temperature increase. Such assessments generally find that economic development and population growth are likely to be the major drivers of natural disaster risk in the future; yet, little is said about changes in vulnerability, generally considered a key component of risk. As well, risk is represented by an estimate of average observed impacts using the statistical expectation. Explicitly accounting for vulnerability and using a fuller risk-analytical framework embedded in a simpler economic model, we study the case of Bangladesh, the most flood prone country in the world, in order to critically examine the contribution of all drivers to risk. Specifically, we assess projected changes in riverine flood risk in Bangladesh up to the year 2050 and attempt to quantitatively assess the relative importance of climate change versus socio-economic change in current and future disaster risk. We find that, while flood frequency and intensity, based on regional climate downscaling, are expected to increase, vulnerability, based on observed behaviour in real events over the last 30 years, can be expected to decrease. Also, changes in vulnerability and hazard are roughly of similar magnitudes, while uncertainties are large. Overall, we interpret our findings to corroborate the need for taking a more risk-based approach when assessing extreme events impacts and adaptation – cognizant of the large associated uncertainties and methodological challenges -.

Acknowledgments

This paper is an outcome of a project sponsored by the IIASA Greenhouse Gas Initiative (GGI), for which we gratefully acknowledge funding.

1. Introduction: Extreme events and climate change

Extreme event risks and options for managing these risks are increasingly receiving attention in international climate change policy. For example, the *Bali Action Plan*, agreed at the 13th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Bali in 2007, addressed identified disaster risk management these issues as a high priority items for an adaptation strategy concern.

> The Conference of the Parties […] decides to launch a comprehensive process […] by addressing […] enhanced action on adaptation, including, inter alia, consideration of […] (ii) Risk management and risk reduction strategies, including risk sharing and transfer mechanisms such as insurance;(iii) Disaster reduction strategies and means to address loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change. (UNFCCC, 2008)

This increased raised concern and focus can be related to increasing empirical evidence as most recently elaborated in the 4th assessment report of the IPCC, which found evidence on increased rising impacts of extremes, such as cyclones and flooding, due to altered intensities and frequencies of these natural hazards (Parry et al., 2007), many of which are expected to increase in frequency or severity in various places in a future warmer climate (Solomon et al., 2007). Yet, there are very few systematic economic studies that cost the impacts and consider the processes of adaptation to extreme weather and climate variability (see e.g. Wreford et al., 2007). So far, extreme event risks have mostly been represented in Integrated Assessment Models (IAM) with global or regional resolution using add-on damage functions that are based on average past observed impacts and contingent on gradual temperature increase (Nordhaus and Boyer, 2000; Hope, 2006; Pielke and Sarewitz, 2005). For example, based on such an assessment, Pielke and Sarewitz (2005) contend that economic development and population growth are likely to be the major drivers of natural disaster risk in the future. Their analysis employs a deterministic globally-resolved approach model using sensitivity analysis of global tropical cyclone losses and contributions to future impacts by societal changes (growth and demography) versus climate change impacts (see figure 1). Based on assumptions derived from the 2nd and 3rd assessments of the IPCC on future loss projections driven by either societal or climatic drivers (with other drivers are held constant), Pielke and Sarewitz contend that societal changes by far trump climatic changes for the four climate scenarios considered (A1, A2, B1, B2) and different studies from the literature considered (see Figure 1).

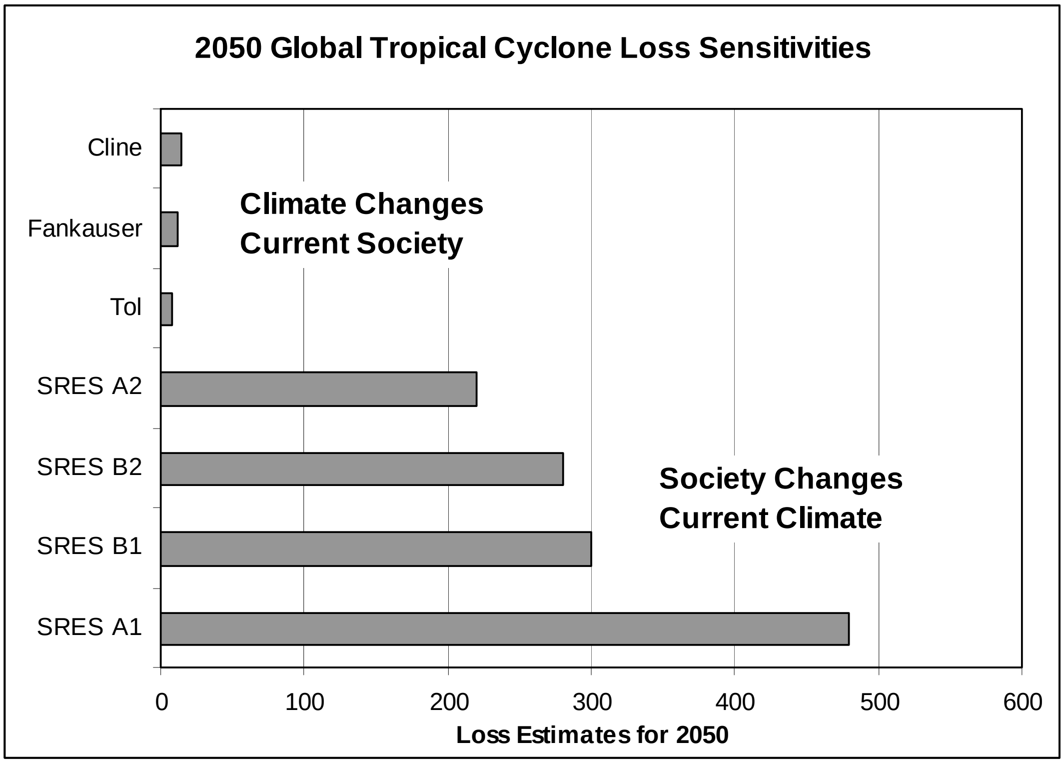


Fig. 1: Study on future increase in global tropical cyclones losses due to societal and climatic drivers[1]. Source: Pielke Jr. and Sarewitz, 2005

We examine whether there is room for improving such assessments and in terms of considering both climatic and societal changes simultaneously. The key question we examine is *how the drivers of social/economic and natural systems affect potential extreme event impacts and risks in the future.* Specifically, we study the relative importance of climate change versus social/economic drivers, such as increasing population and vulnerability, in current and future disaster losses. We address these issues based on analysis by the IIASA CATSIM (Catastrophe Simulation) model focusing on Bangladesh, the probably most flood-prone country in the world. CATSIM is a simple *risk-based* economic model designed to account for the direct monetary and indirect macroeconomic effects of natural disasters as well as allowing to study the costs and benefits of risk management options. We assess projected changes in riverine flood risk in Bangladesh up to the year 2050 and attempt to quantitatively assess the relative importance of climate change versus socio-economic change in current and future disaster risk. Overall, we find changes in vulnerability and hazard to be of

---

[1] The three lower bars identify three different calculations (named for the authors of those assessments) as reported in the Second Assessment Report of the IPCC for tropical cyclone-related damage in 2050 (compared to 2000) as a function of climatic changes and independent of societal drivers. The four top bars compare tropical cyclone-related damage in 2050 to 2000 for societal (population and wealth) drivers as based on the four SRES scenarios of the 3rd Assessment Report of the IPCC irrespective of changes in climate.

different magnitudes; what is more, while flood frequency and intensity, based on regional climate downscaling, are expected to increase, vulnerability, based on observed behaviour in real events over the last 30 years, can be expected to sharply decrease.

A key entry point for our analysis is the fact that substantial progress has been made over the last few years in modeling extremes in a risk-based, more geographically explicit manner harnessing recent innovations and improvements in modeling techniques and data (for example, see Jones, 2004). Regional climate modeling and statistical downscaling methods, as well as climate and socio-economic downscaling techniques, which are more appropriate for analyzing localized extreme event patterns, can increasingly be made use of (Goodess et al., 2003). We would argue that it is important to apply these methods within a risk-analytic approach for assessing natural disaster risk as a convolution of geophysical signal, socioeconomic drivers and vulnerability that generate natural hazards via loss-frequency functions. Such a stochastic representation (with a discussion of parameter uncertainties) of extreme event risks more appropriately reflects the low-probability, high consequence nature of such events and its associated potential socio-economic impacts.

Beyond academic curiosity, Modelling drivers of disaster risks more (spatially) explicitly has policy relevance and may help to may inform pertinent country level adaptation decisions on local or national levels, for which there seems to be critical need. In Bali, in another potentially path-breaking decision, the *Adaptation Fund* was created, which will help fund concrete adaptation projects under which (own emphases in bold):

> […] developing country Parties to the Kyoto Protocol that are *particularly vulnerable* to the adverse effects of climate change are eligible for funding from the Adaptation Fund to assist them in meeting *the costs of adaptation*…(for) concrete adaptation projects and programmes that are *country driven* and are based on the *needs*, views and priorities of eligible Parties. (UNFCCC, 2008)

Burning key issues to be addressed if adaptation funding is to be released under such a fund requires analyses relate to of (i) the need for and opportunities of locale-specific, concrete adaptation and (ii) the scope for, and the costs and benefits of such adaptation. Our research hopes to make a contribution to these scientific and policy relevant issues. The key question we are examining is *how the drivers of social/economic and natural systems affect potential extreme event impacts and risks in the future.* Specifically, we examine the relative importance of climate change versus social/economic drivers, such as increasing population and vulnerability, in current and future disaster losses. We address these issues by focusing on Bangladesh, as the most flood-prone country in the world based on analysis by our CATSIM (Catastrophe Simulation) model.

The paper is organized as follows. In section two, we discuss the modelling approach, including a discussion of the CATSIM model. In section three, we turn to assessing direct risk (losses) in Bangladesh, before we turn to the economic risk assessment in section four. Finally, in Section five we conclude with insights gained from the model estimates and the modelling process.

2. Modeling approach: Extreme Risks, Indirect Effects and Risk Management

2.1 Assessing extreme event risk

Natural disaster risk is commonly defined as the probability of potential impacts affecting people, assets or the environment. As to the drivers of risk, the standard approach for estimating natural disaster risk and potential impacts is to understand natural disaster risk as a function of hazard, exposure and vulnerability (e.g. see UNISDR, 2005).

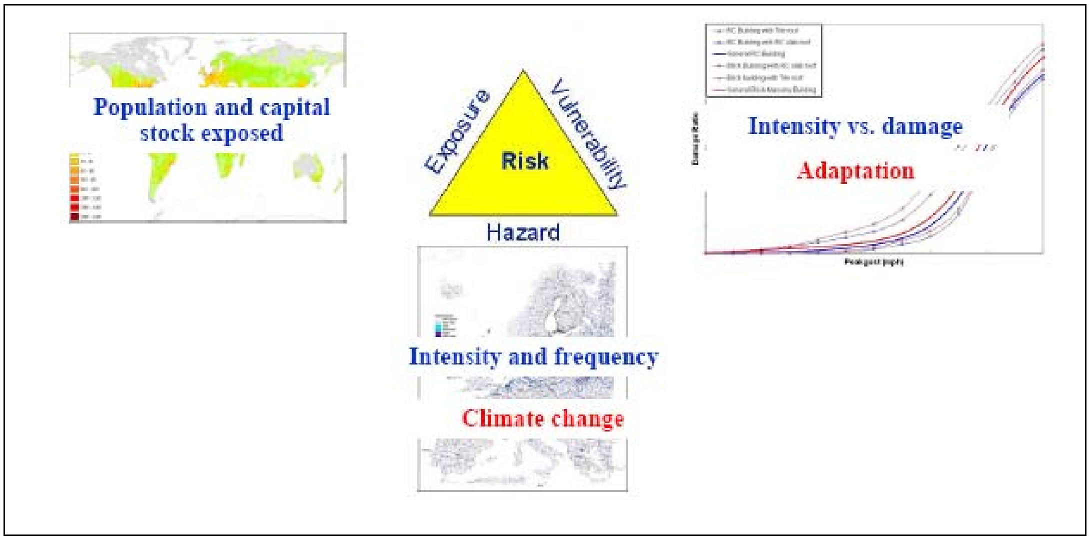


Fig. 2: Modelling risk

Hazard analysis involves determining the type of hazards affecting a certain area with specific intensity and recurrency. Assessing exposure involves analyzing the relevant elements (population, assets) exposed to hazard(s) in a given area. Vulnerability is a multidimensional concept encompassing a large number of determinants that can be grouped into physical, economical, social and environmental factors. The following factors affecting and comprising vulnerability can be listed:

- Physical: related to the susceptibility to damage of engineering structures such as houses, dams or roads. Also factors such as population growth may be subsumed under this category.
- Social: defined by the ability to cope with impacts on the individual level as well as referring to the existence and robustness of institutions to deal with and respond to natural disaster.
- Environmental: a function of factors such as land and water use, biodiversity and stability of ecosystems.

- Economic: refers to the economic or financial capacity to refinance losses and recover quickly to a previously planned activity path. This may relate to private individuals as well as companies and the asset base and arrangements, or to governments that often bear a large share of a country's risk and losses.

In the following analysis we focus on physical and economic vulnerability. Before turning to the discussion of the CATSIM model, we review the literature on the empirical evidence of economic disaster impacts and approaches for modelling such economic risks.

2.2 Empirical evidence on the macroeconomic impacts of disasters

The "disaster management" literature concentrates on the significant effects disasters may cause in terms of loss of life physical destruction and monetary losses; furthermore, a smaller literature addresses the economic of disasters and finds significant follow-on economic effects in terms of micro and macroeconomic impacts. We focus on the latter which can be summarized as follows (see Mechler, 2004).

- No significant macroeconomic impacts are found for developed countries. In developed countries, the literature focuses generally on the direct and indirect impacts and on the regional economies.
- In developing countries, GDP falls in the year of the event or the year after, but rebounds in successive years due to increased investment and capital inflows.
- The public deficit increases due to increased spending needs and decreased tax revenue.
- The trade balance worsens, as less exports are undertaken and more imports are demanded. Also, a worsening of the trade deficit is usually reported, as imports rise (need for additional goods) and exports fall (destruction of goods produced and productive capital stock) post-catastrophe.
- Significant longer-term impacts are to be expected depending on the size of event, economic vulnerability, and prevailing economic and socio-political conditions, as key resources are diverted to relief and reconstruction.
- The inflow of external aid and capital is decisive for the speed of economic recovery.

For example, for a sample of large disaster events in heavily exposed, developing countries, Hochrainer (2006, 2009) finds important GDP effects, when comparing actual to projected GDP in the fourth year after the event (event marked by important asset losses) to actual GDP (see Figure 3).

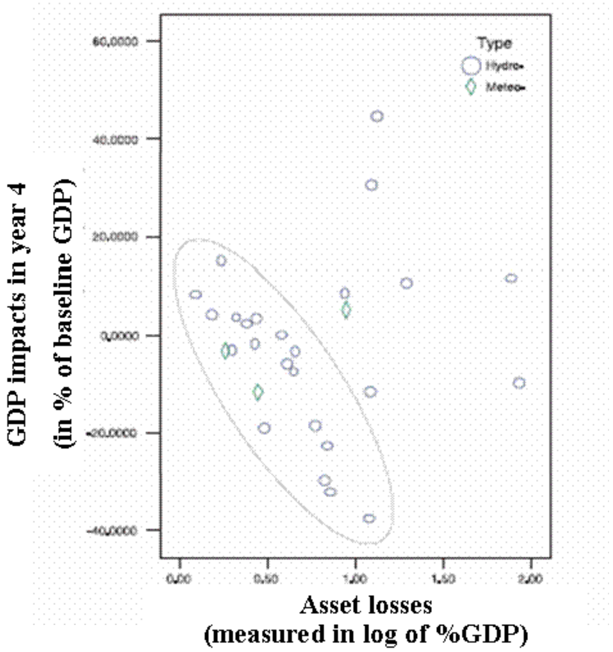


Fig. 3: GDP changes in year 4 after a disaster vs. asset losses. Source: Hochrainer, 2006

2.3 Economic modelling related to assessing extreme event risk

Before discussing the modelling approach we give a snapshot over the literature on economic modelling approaches for assessing economic disaster risks in order to provide motivation for CATSIM approach chosen. The review is broken down into work conducted in the disaster risk management and climate adaptation communities

Economic modelling and disaster risk management

There is a substantial, yet very heterogeneous body of modelling research on the economic impacts disaster risk management community (e.g. Yezer and Rubin, 1987; Ellson et al., 1984; West and Lenze, 1994; Brookshire et al., 1997; Chang et al., 1997; Guimaraes et al., 1993; Rose 1997; Freeman et al., 2002a; Mechler, 2004; Hochrainer, 2006; Noy, 2009). Existing approaches utilize a plethora of models such as Input-Output, Computable General Equilibrium, economic growth frameworks and simultaneous-equation econometric models. While these modelling approaches find substantial economic repercussions of natural disasters in less developed economies in line with empirical evidence, other studies estimate the aggregate impacts on national economies in developed countries to be close to zero, yet find important distributional and sectoral effects, e.g. on the housing market, or effects due to the interruption of services.

Okuyama (2007) discusses the pros and cons of these models, which is summarized in table 1 and contrasted with the CATSIM model approach. One issue with the modelling undertaken in this line of research is the deterministic nature of the modelling approaches. In essence, disaster risks often are represented as averages (expected annual losses), or singular events in the past are remodelled. This does not lend itself to a forward-looking and more comprehensive analysis of risk and may lead to a serious underestimation of the potential consequences of natural disasters, which by “nature” are low-probability-high impact events. Also, the modelling has mostly been developed to address more developed countries' issues and interest on sectoral and distributional impacts of disasters. In contrast, CATSIM is a risk-based modelling framework which can be used to address planning issues for less developed countries and governments.

Table 1: Modelling the effects of disaster risk

Approach	**Question addressed**	**Pros**	**Cons**	**Application**
Deterministic				
Input-Output (I-O)	Interdependencies within a regional developed economy	Based on actual data, simplicity	Rigid structure with respect to input and import substitutions, a lack of explicit resource constraints, and a lack of responses to price changes	In conjunction with transportation network models, lifeline network models, and comprehensive disaster assessment model, namely HAZUS
Computable General Equilibrium (CGE)	Sectoral and price effects within a regional developed economy	Non-linear, can respond to price changes, can incorporate input and import substitutions, and can explicitly handle supply constraints	Rather intended for long-run equilibrium may lead to underestimation of economic impacts due to its optimizing behaviour features	…Several
Social accounting matrix (SAM)	Higher-order effects across different socio-economic agents, activities, and institutions within a regional developed economy	distributional impacts of a disaster in order to evaluate equity considerations for public policies against disasters	Rigid coefficients and it tends to provide upper bounds for the estimates	Distribution of impacts among economic agents…
Econometric models	Various	Statistically rigorous, can provide stochastic estimates, and have forecasting capabilities	Appear ill-suited for disaster impact analysis when not including any major disaster experiences,	Estimates of impacts of major earthquakes in the United States
Risk-based				
CATSIM	Contingent liability planning for public sector risk in vulnerable developing countries	Risk-based flexible planning framework	Simple economic framework, focus on financial aspects and produced capital	Developing countries exposed to disaster risk

Source: based on Okuyama (2007)

Economic modelling and the climate adaptation community

The analysis of extreme events and their potential impacts has gained in importance in the climate change modelling community, among other reasons due to increasing empirical evidence about the increased impacts on account of altered intensities and frequencies of extremes such as cyclones and flooding (Parry et al., 2007). A more risk-based approach has recently been embraced (for example, see Jones, 2004), and regional climate modeling and statistical downscaling methods as well as climate and socio-economic downscaling techniques, which are more appropriate for analyzing localized extreme event patterns, can increasingly be made use of (Goodess et al., 2003). Yet, the representation of extreme event risk and adaptation within modelling approaches including Integrated Assessment Modelling is still emerging. Also, assessments of climate change impacts and vulnerability have changed in focus from an initial analysis of the problem to the assessment of potential impacts to a consideration of specific risk management methods (Parry et al., 2007). Yet, there is considerable scope for making better use of improved modelling capacity and available data on extreme event impacts and risks. The recent Stern review is at the forefront of such research and proposes to adopt a modelling approach compatible with the economics of risk, based on the proposition that averaging across outcomes conceals risks (Stern, 2007). Such an approach is particularly important for catastrophic impacts that are potentially large, uncertain, unevenly distributed and may occur in the distant future. For example, the PAGE2002 integrated assessment model used in the Stern review takes a stochastic approach using Monte Carlo simulation for varying climatological parameter values and generates a probability distribution of future outcomes, such as income, accounting for climate-driven damage and adaptation costs, which are subtracted from baseline GDP growth projections. Yet, based on work by Nordhaus and Boyer (2000) extreme event risks are represented in a rather ad-hoc manner via add-on damage functions that are based on average past impacts and contingent on gradual temperature increase. With global mean temperatures rising, large GDP impacts are beginning to appear and the probability of large losses is estimated to roughly increase by 10% per degree increase in temperature beyond 5 degree warming. There are no feedbacks from the impacts of climate change to the socio-economic drivers (production, consumption, demographics) of emissions and climate change, which implicitly results in the assumption that climate impacts are marginal and do not affect the social system. Finally, adaptation is not considered explicitly (Stern, 2007).

2.4. The CATSIM Approach to Estimating Economic Disaster

We suggest that important progress can be made in modeling extremes in a risk-based, more geographically explicit manner harnessing recent innovations and improvements in modeling techniques and data and harnessing insights of climate change and natural hazards modeling community for assessing natural disaster risk as a function of a geophysical signal, socioeconomic drivers and vulnerability accounting for the inherent aleatoric (chance) variability of natural hazards via loss-frequency functions. Such a stochastic representation (with a discussion of parameter uncertainties) of extreme event risks more appropriately reflects the low-probability, high consequence nature of such events and its associated potential socio-economic impacts. This is the first attempt to explicitly model direct and indirect effects as well as the inherent uncertainty of the estimates on the macro-scale and providing risk management strategies on the country level.

The IIASA approach making use of the CATSIM (CATastrophe SIMulation Model) model takes such a direction. Catastrophe models typically generate probabilistic losses by simulating stochastic events based on the geophysical characteristics of the hazard and combining the hazard data with analyses of exposure in terms of values at risk and vulnerability of assets. CATSIM aims at filling important gaps on work on probabilistic *economic* impacts of natural disasters by representing a simple *risk-based* economic framework for accounting for the macroeconomic impacts due to natural disasters as well as allowing to study the costs and benefits of measures for reducing those impacts (Hochrainer, 2006; Mechler et al., 2006). CATSIM uses Monte Carlo simulation of disaster risks in a specified region and examines the ability of the government and private sector to finance relief and recovery. It is interactive in the sense that the user can change the parameters and test different assumptions about the hazards, exposure, sensitivity, general economic conditions and a country's ability to respond. As a capacity building tool, it can illustrate the tradeoffs and choices the authorities confront in increasing their resilience to the risks of catastrophic disasters. Figure 4 summarizes the steps to be taken in graphical format. The blue part of the Figure represents the direct risk assessment part, which uses a dynamic approach for assessing future losses, the green area marks the (macro-) risk management part, were indirect, economic risk are estimated.

In a nutshell, CATSIM goes through the following stages (more detail is provided further below). In stage 1, the risk of direct losses in terms of the probability of asset losses in the relevant country or region is assessed as a function of hazard (frequency and intensity), the elements exposed to those hazards and their physical vulnerability. Based on the information on direct risks, financial resilience can be evaluated by assessing a country's ability to finance its obligations for the specified disaster scenarios (stage 2). Financial resilience is directly affected by the general conditions prevailing in an economy, e.g. the budget stance and changes in tax revenue have important implications on a country's financial capacity to deal with disaster losses. A main question here is whether a country and government is financially prepared to repair damaged infrastructure and provide adequate relief and support to the private sector for the estimated damages. For this assessment (stage 3), it is necessary to examine the financing sources; both sources that will be relied on (probably in an *ad hoc* manner) *ex post* after the disaster, and sources put into place before the disaster (*ex ante*). Comparing available financing with post-disaster financial obligations yields an estimation of the potential *resource gap.* To assess the possibility of a resource gap for a longer time horizon, there is also the possibility to attach probabilities to the resource gap, e.g. one could find that in the current situation there is a 10 percent probability that a resource gap will occur in the next 10 years. This result can serve as a baseline to compare different risk management strategies which would decrease this probability. Financial vulnerability can have serious repercussions on the national or regional economy and the population (stage 4).

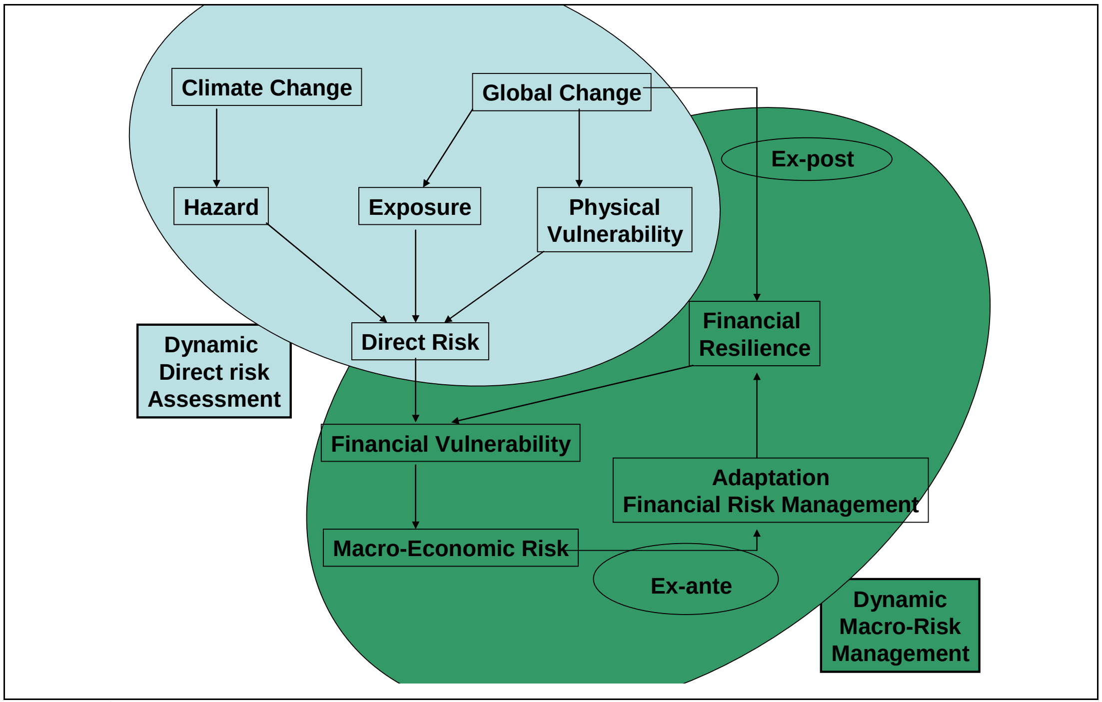


Fig. 4: Extended CATSIM methodology, separated into dynamic direct risk and dynamic macro risk assessment and management.

If damaged infrastructure, for example roads and hospitals, cannot be replaced or repaired and limited assistance is extended to those in need after a disaster, there will be longer-term consequences. Our main impact channel for disasters affecting the economy is via impacts on capital stock. The pros and cons of investing in risk management instruments for reducing and financing disaster risk before the occurrence of actual events are dealt within stage 5. Some focus in CATSIM is on financial mechanisms. Budgetary resources allocated to catastrophe reserve funds, insurance and contingent credit (as well as to preventive loss-reduction measures) reduce the potential resource gap, and thus can ensure a more stable development path. On the other hand, ex ante financing and prevention measures come at a price in terms of other investments foregone and will inevitably have an adverse impact on the economic growth path of an economy. The model assesses this trade-off by comparing the costs of selected ex-ante measures with their benefits in terms of decreasing the possibility of encountering a resource gap.[2]

Generally, there is substantial uncertainty in catastrophe modelling approaches, as data on disaster events, return periods, loss of life, economic losses etc. are by definition limited as disasters are rare events. Furthermore, data have to be used with caution as there may be biases, and issues such as timing of reporting plays a role. For example, often economic losses are reported within a few days time after an event,

---

[2] Four ex ante financing policy measures are currently considered in the CATSIM tool: Excess of loss insurance, contingent credit, reserve funds and cat bonds. Also, one generic option for loss reduction measures has been implemented in order to analyze the linkage with risk financing. Optimal portfolios can be calculated to decrease risk as much as possible but subjected to budget and growth constraints. This will increase the financial resilience and therefore decrease its economic risk.

where it is virtually impossible to get a full overview over the sheer extent of the event, and often not adjusted significantly.

3. Direct flood risk assessment

We now turn to applying CATSIM to the case of Bangladesh, probably the "hotspot" flood country. Riverine flood risk is the dominant disaster type in Bangladesh and other hazards are tropical cyclones, sea surges and earthquakes. Bangladesh lies at the confluence of three large rivers, the Ganges, the Brahmaputra and the Meghna, and is often referred to as one massive river delta.

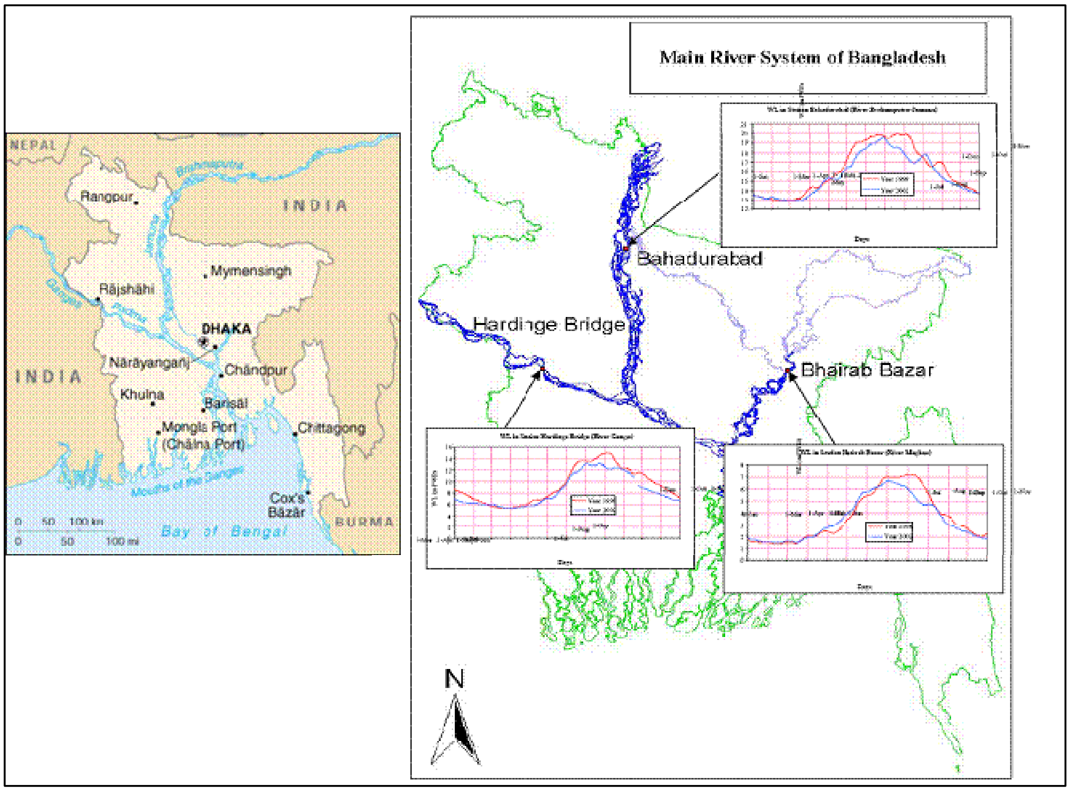


Fig. 5: Key river systems in Bangladesh. Source: Tanner et al., 2007

River flows usually exceed the capacity of the drainage channels and as a result Bangladesh is considered the most flood vulnerable country in the world. About 26 percent of the country is subject to annual flooding and an additional 42 percent is at risk of floods with varied intensity. Extreme floods occurred in 1974, 1980, 1984, 1987, 1988, 1998, and 2004. For example, the 1998 flood affected 68% of the country and seriously impacted the livelihoods of 30 million people while lasting for over 10 weeks. There have been important micro and macroeconomic repercussions. Benson and Clay (2002) show that natural disasters have had significant development implications, particularly so on the agricultural sector due to the sheer destruction and the diversion of resources away from investments into productive projects supporting long-term development. Also, they empirically showed that both agricultural and non-agricultural economic vulnerability has been decreasing over time.

Further, for Bangladesh most models indicate higher rainfall intensities causing higher peak flows in rivers and increases in flood magnitude and frequency for a warming climate. For example, flow records over 50 years long for the station Bahadurabad (Brahmaputra/Jamuna rivers) show that peak discharge increasing with earlier peaking. The average timing of the peak was in the middle of August but is now in the first week of August. At the station Bhairab Bazar (Meghna), peak discharge has been decreasing and delaying slightly as it has moved to the last week of September from mid July in the late 1970s. At the station Hardinge Bridge on the Ganges, peak discharge has been increasing but the time of peak is advancing (delaying).

3.1 Modeling Climate and Global Change Effects on Extreme Risks

The assessment for Bangladesh builds on work in a multi-partner project in a DFID sponsored project on climate risk screening in Bangladesh (ORCHID) where IIASA contributed on the costs and benefits of disaster risk management and climate adaptation. (see Tanner et al., 2007).[3] Table 2 lists information in key modules and their sources.

Table 2: Data and sources used

Module/input data	Exogenous driver	Source
Mean temperature change, Precipitation and change	Temperature	PRECIS Regional climate model for SRES A2
Max. discharge	Precipitation	Statistical hydrological model
Flood impacts, Vulnerability	-	Bangladesh statistics
Flooded area	Maximum discharge	Statistical model
Exposure		GDP, Population, assets
Risk (financial losses)	Flooded area	CATSIM extended
Vulnerability	Risk Economic resilience	CATSIM extended
Economic Risk	Risk Economic Vulnerability	CATSIM
Risk Management/adaptation	-	CATSIM

---

[3] Contributors to the ORCHID study were:
Institute of Development Studies (IDS), University of Sussex, UK; CEGIS – Center for Environmental and Geographic Information Services, Bangladesh; Bangladesh Institute of Development Studies (BIDS), Bangladesh; School of Development Studies-Overseas Development Group, University of East Anglia, UK; Tyndall Centre for Climate Research, University of East Anglia, UK; International Institute of Applied Systems Analysis (IIASA), Austria; Bangladesh Unnayan Parishad (BUP), Bangladesh; Bangladesh Centre for Advanced Studies (BCAS), Bangladesh.

Based on the generic CATSIM approach, we produced an extended version which explicitly incorporates climate and global changes in the future. Climate change and global change will change the driving factors of the direct risk, e.g. loss of assets or loss of life. Climate Change, e.g. increasing temperature, will affect potential hazards in the future and therefore will change the direct risk either by increasing/decreasing the frequency and/or intensity in the future. On the other hand, global change, e.g. economic development and population change, will also affect the elements at risk and the physical vulnerability of the assets. Figure 6 shows the new approach how losses will change over time due to climate and global changes.

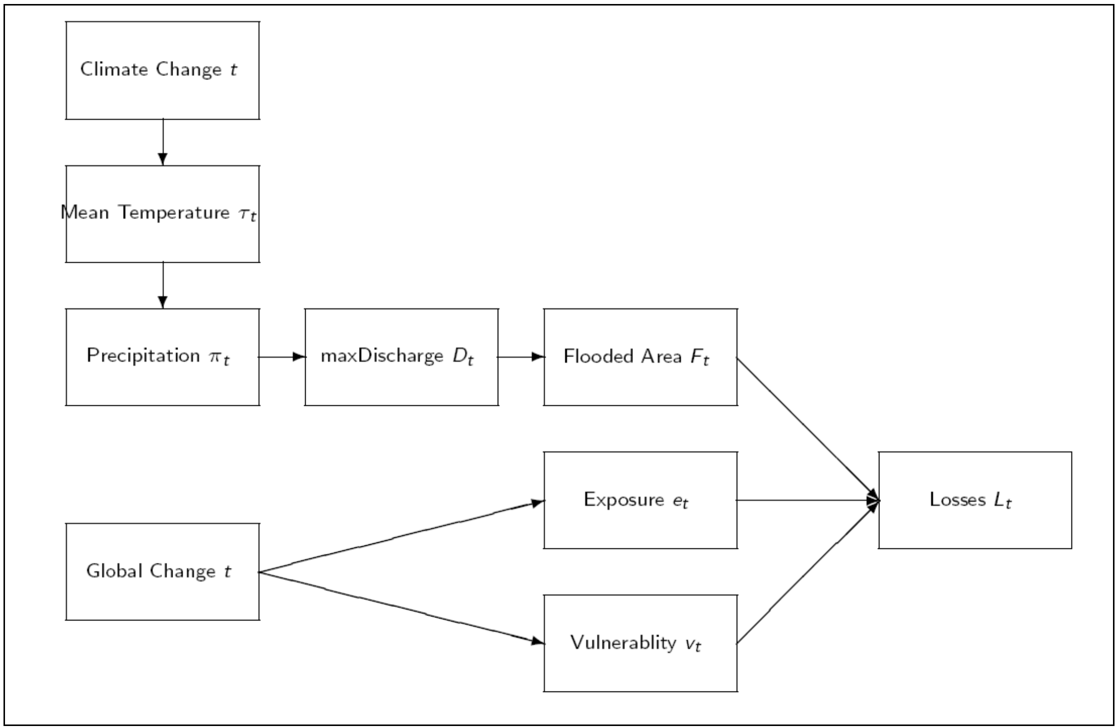


Fig. 6: Methodology for the dynamic assessment of future losses due to global and climate changes

Putting all this together will have a cumulated effect on the financial vulnerability and risk management options the government can or will want to take place in the future (steps 2, 3 and 4). The main challenges for this approach are to determine the quantitative relationship between climatic and global related issues with risk and risk management strategies within a generic framework which is non-stationary over time. The principal relationships of the variables as shown on Figure 6 are as follows:

- Climate change leads to a change in temperature,
- temperature affects precipitation,
- Precipitation leads to specific discharge levels,
- Discharge levels lead to affected flood areas,
- Affected flood area is coupled with losses experienced.

Losses will also be affected not by climatic events and climate change but by global changes bearing upon exposure income increases and demographic changes:

- Economic development and demographic change leads to changes in exposure
- Exposure affects losses

Furthermore, it can not be assumed that the physical vulnerability which affects the elements at risk stay the constant over time. Therefore,

- Economic development changes physical vulnerability, and a
- A changed physical vulnerability finally leads to reduced direct risk.

Hence, direct losses are a function which changes over time due to the driving factors hazard, exposure and vulnerability which will be affected by climate and global changes. Overall, the operationalisation of the direct risk assessment can be represented as follows (figure 7).

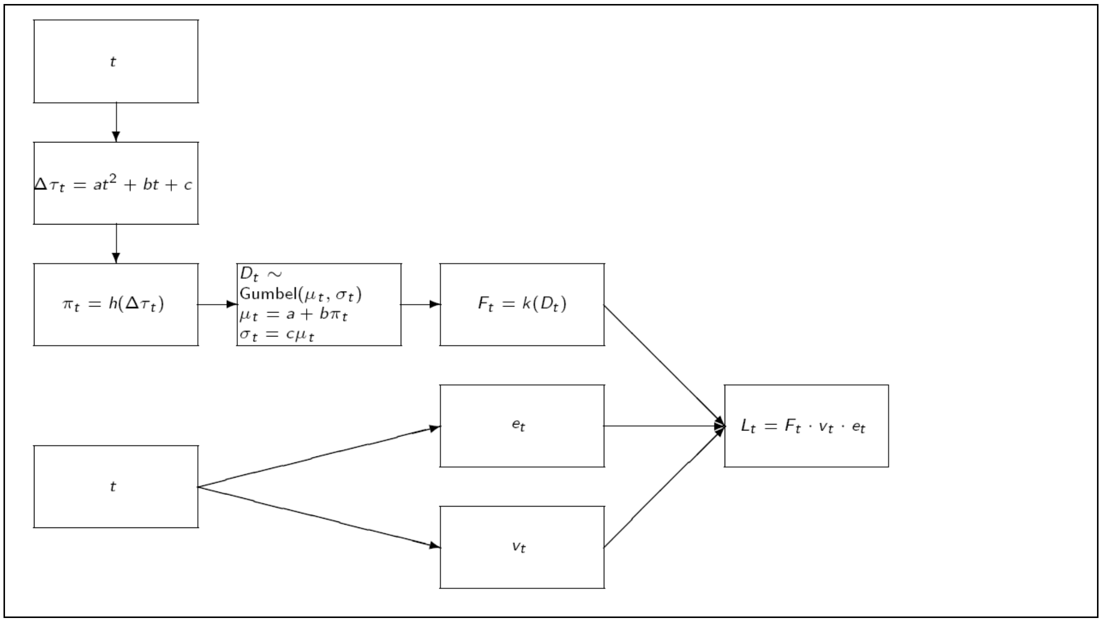


Fig. 7: Operationalization of the direct risk assessment

The change in temperature will result in changes of precipitation which will be based on the Tanner et al. (2007) analysis. Based on empirical observations, the rainfall changes will affect discharge levels which ultimately lead to changes in the flooded area. The last relationship is estimated based on nonlinear regression analysis of past data. Furthermore, the changes in vulnerability will be based also on past losses and the relationship found, will be used for projections into the future. In the next sections each of the hazard, exposure and vulnerability components will be explained in detail.

3.2 The Hazard Module

In the model, discharges in the three river systems are compounded into one statistical model (the “GBM river basin”) (see Tanner et al, 2007). The Brahmaputra contributes the greatest volume with 58 percent, while the Ganges and Meghna contribute about 32 percent and 10 percent, respectively. The seasonal distribution of the flow is about 50% of the total volume and passes through Bangladesh in June to August. Usually, one distinguishes between the months of December, January and February (DJF), usually the winter months and the months of June, July and August, the monsoon months (JJA). The line of dependence is as follows: Temperature change is a driver for precipitation change, precipitation change is a driver for peak discharge change, and peak discharge change is a driver for flooded area change. As already said we use simple relationships between the variables based on statistical estimates and also rely on results from the Tanner et al. (2007) project for determining changes in flooded areas due to climate change. The quantitative relationship between years and temperature change is dependent on the models and the storylines which are used. Here, we focus on the SRES A2 scenario, which has standardly been taken as a reference scenario in many analyses (Nakicenovic et al., 2000). The temperature changes for 2020 and 2050 are shown in the following table 3 and are based on the Tanner et al.(2007) analysis.

Table 3: Temperature change in the Basin for the A2 Scenario

Absolute temperature change (°C)	**2020s JJA**			**2050s JJA**		
GBM Basin – A2	**T**	**P %**		**T**	**P %**	
Mean	1.04	3.79		2.04	8.54	
High (wet)	0.36	7.87		0.78	26.12	
Low (dry)	1.45	2.78		2.78	7.2	

Source: Tanner et al. (2007)

We use a simple relationship (polynomial form of degree 2) between years and temperature change which are based on the table above and the JJA months. The relationship between temperature change (over mid 20th century levels) and change in precipitation change (%) is also modelled based on three GCMs (CSIR09, HadCM3, GFDL) for each of the rivers. Furthermore, the relationship between precipitation change and (average) mean peak discharge is also modelled based on the three GCMs (CSIR09, HadCM3, GFDL) for each of the rivers. Furthermore, we use a Poisson model for the event frequency and a Gumbel model for the event severity. The relationship between the flooded area and the discharge levels was estimated within a nonlinear regression model. The Gumbel distribution is defined as,

$$F(x) = \exp(-\exp(-x))$$

A location and scale change re-parameterization (Fisher-Tippet) yields, the following distribution,

$$F_{\mu,\sigma}(x) = \exp(-\exp(-\left(\frac{x-\mu}{\sigma}+\gamma\right)\pi/\sqrt{6}))$$

with $\gamma = \lim_n \left[\sum_k \frac{1}{k} - \log n \right] = 0.5772$

Based on past max discharge levels and flooded areas, the Gumbel distribution for the max discharge and the non-linear function for flooded area are estimated (see figure 8). Based on the Tanner et al. study, the parameter σ is changed over the time period, based on the minimum and maximum values of the flooded area for a given year till year 2020 and held constant afterwards.

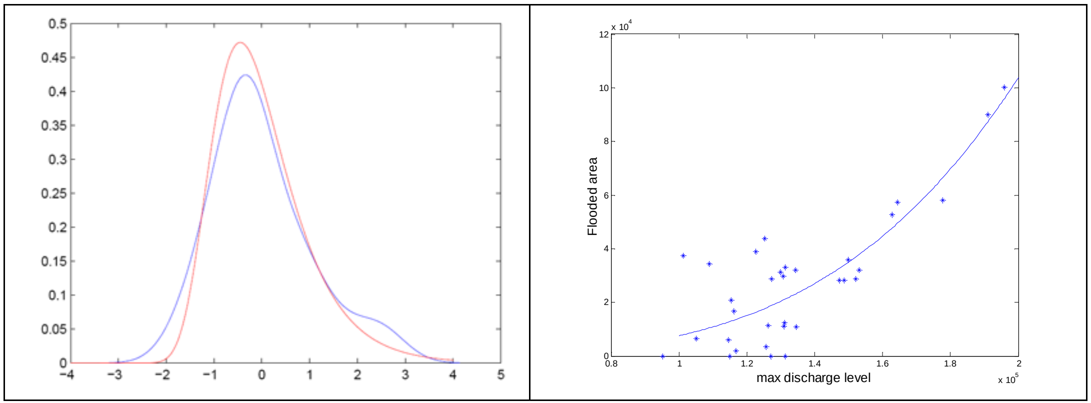


Fig. 8: Left-hand side: Estimation of the Gumbel distribution for the max discharge levels. [Blue line: density estimate, red line: fitted distribution). Right-hand side: Estimation of the function $F_t = bD_t^{\alpha}$]

Maximum discharge on the other hand is estimated using the peak discharge levels from the three rivers. The linear relationship seems to be quite robust due to the nearly same estimated changes in all GCM models (R square is above 95 percent for all three rivers). Hence, the following relationships are used:

- $QMax\_G = 603.48\Delta P + 52623$
- $QMax\_B = 535.59\Delta P + 69271$
- $QMax\_M = 227.73\Delta P + 14084$
- $QMax\_total = QMax\_G + QMax\_B + QMax\_M$

Summarizing, according to figure 6 we found the following estimated relationships (table 4):

Table 4: Parameter estimates for the Hazard model.

Temperature Change	$\tau_t = \tau_{1950} + 0.000185t^2 - 0.718t + 699$
Precipitation as a function of temperature	$\pi_t / \pi_{1950} = 0.542(\tau_t - \tau_{1950})^2 + 3.08(\tau_t - \tau_{1950})$
Location scale parameter of the Discharge distributions	$\mu_t = 131978 + 1.366,8\pi_t / \pi_{1950}$ $\sigma_t = 0.1751\mu_t$
Flooded area as a function of the discharge level	$F_t = 1.2621\left(\frac{D_t}{10000}\right)^{3.778}$

Source: Own calculations, Tanner et al. (2007).

3.3 The Exposure Module

Exposure projections in the future are based on the SRES scenarios and therefore again depend on the storyline chosen (here A2). In the SRES scenarios the exposure is defined as GDP at market exchange rates (MER) and total population in Bangladesh for the time period between 2000 and 2100.

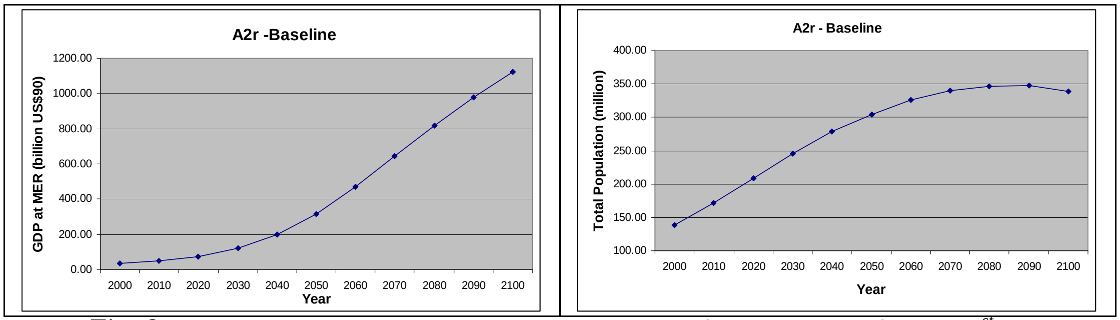


Fig. 9: Projected GDP and population trajectories for Bangladesh for the 21st century for SRES A2scenario. Source: Nakicenovic et al. (2000)

The exposure model renders the given exposure level for year t to the loss model.

3.4 The Vulnerability Module

The vulnerability module calculates the physical vulnerability indicator for a given year. We look at vulnerability in terms of potential monetary losses for an event of a given return period. It is based on statistical analysis of past losses given flooded area, exposure and economic situation. For the given study we had to rely on the following data points on impacts and modified as discussed in Tanner et al. (2007).

Table 5: Selected impacts for worst floods in Bangladesh over the last 33 years

Year	Asset losses (million current US$)	Fatalities	Affected (million)	Affected country (‘000 sq km)	Houses damaged (‘000s)	GDP current (million US$)	**Estimated return period (years) per Islam, 2005**
1998	2128	918	31	100	2647	44092	**90**
1988	1424	2379	47	90	2880	26034	**55**
1987	1167	1657	30	57	989	23969	**13**
2004	1860	285	33	56	895	55900	**12**
1974	936	28700	30	53	Na	12459	**9**
1984	378	1200	30	Na	Na	19258	**2**

Data sources: Islam 1997, 2000, 2005, 2006; EMDAT, 2007; WDI, 2006.

Information on impacts in terms of asset losses were set in relation to GDP in the year of the event to calculate losses in relative terms independent of exposure and changes therein. People and societies are continuously bracing themselves for natural hazards and aiming at reducing vulnerability; these vulnerability-reducing efforts can readily be discerned in the statistics: The 1998 flood event, considered the largest event so far with an estimated recurrency period of 90 years, incurred relative asset losses of 4.8% of GDP, whereas those losses were much higher in the 9 year floods of 1974. Similarly, fatalities were reduced strongly in the 1998 event (ca. 900) with a much stronger hazard intensity compared to the 1974 disaster (ca. 29,000 dead).

In establishing such a curve, it should be noted that vulnerability, exposure and hazard are dynamic forces and subject to change over time. For example:

- Hazards may intensify due to changed weather patterns (e.g. due to climate change),
- Vulnerability may change as
    - Exposure may change due to higher asset concentration, population growth or migration, or/and
    - Fragility can change, as e.g. more protective measures are put into place or houses are built in a more disaster-proof way.

Changes in hazard are discussed in the following and the changes in asset and population exposure is accounted for as values used are relative to population and GDP. Yet, fragility needs to be accounted for as discussed above. For this component of risk, the relative GDP losses per area affected are taken as a first order proxy, which considers the degree of damage and area affected the intensity of the event. Based on these assumptions, risk can thus be normalized to current conditions by dividing relative losses per GDP by this indicator, and a loss exceedance curve for today's risk (2008) drawn. The result is a standard downward sloping loss-frequency curve (low probabilities of high consequences and vice versa).

Table 6: Deriving a representation of current risk for Bangladesh

Description	Economic risk in relative terms adjusted for asset exposure	Proxy for hazard and intensity	Economic risk adjusted for exposure and hazard	Economic risk adjusted for exposure and hazard	
Year	**% GDP**	% area affected	rel losses/area affected	**Current risk: normalized to 2008**	Estimated return period (years) per Islam, 2005***
1998	**4.8%**	68.0%	0.030	**6.0%**	90
1988	**5.5%**	62.0%	0.051	**5.4%**	55
1987	**4.9%**	40.0%	0.055	**3.5%**	13
2004**	**3.3%**	38.0%	0.009	**3.3%**	12
1974	**7.5%**	37.0%	0.957	**3.2%**	9
1984	**2.0%**	-	-	-	2

* Fatalities were related to population of 10 million to arrive at similar magnitudes as the asset losses.

** 2004 conditions were used as representative for 2008, as this is the last data point with impact data.

*** The return periods are estimated in relation to affected areas.

Figure 10 shows how this proxy variable decreases over time for the major floods over the last 33 years. As a comparison, fatalities in those events per 10 million inhabitants are displayed as well, showing the progress made in protecting lives from about 29,000 people killed in a flood in 1974 compared with 285 in 2004. When taking this indicator as a proxy of fragility, the losses can be adjusted for vulnerability-reducing efforts by dividing this proxy value in the year of the event by the value of the last year in the dataset (=2004). For example, for the 1974 floods, a value of 2.32 is calculated in this way. This could roughly be interpreted as the potential degree of damage (fragility) in 1974 being 230% of that in 2004.

Dividing the relative asset losses (column 1) by these fragility proxies would lead to an adjusted value for the relative asset losses and is shown in the next to last column for the events where values were available. In this fashion, a more realistic estimate of risk as represented by the loss-frequency function is arrived at. As figure 10 shows, this adjusted curve is a regularly downward sloping schedule with highest potential losses for the 90 year event (6% of GDP) and lowest for the 9 year event with 3.2% of GDP.

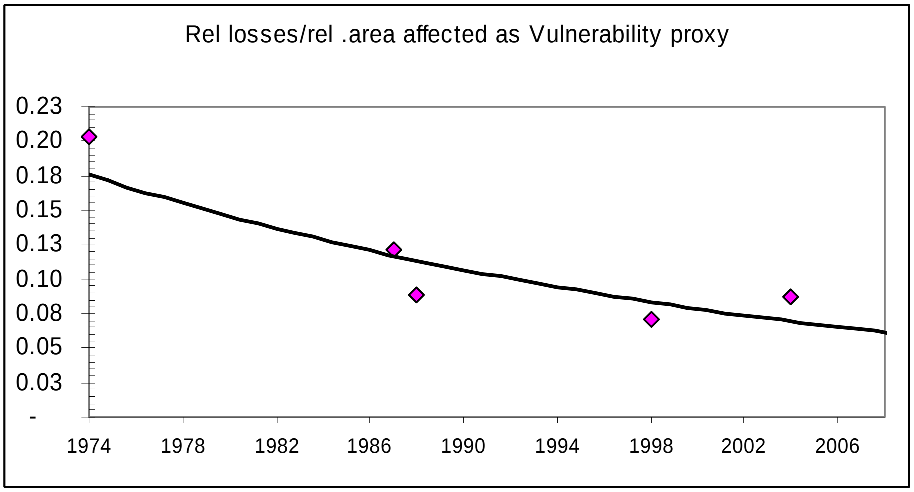


Fig. 10: Vulnerability function based on 5 past natural disaster events in Bangladesh. Source: Own calculations

Figure 11 shows such a vulnerability curve in terms of relative losses (losses per GDP in a given year in terms of area affected (which we use to represent intensity of the event). We find vulnerability strongly decreasing in Bangladesh as over the last years heavy investments have been made in rendering the population and economy more resilient to natural hazards (see e.g. Benson and Clay (2002)). A decreasing function is used to approximate the vulnerability index for future years. To relate the area affected and the fragility with the relative impact (in percent) to the assets the following curves are approximated for 2020 and 2050, again based on the Tanner et al.(2007) data.

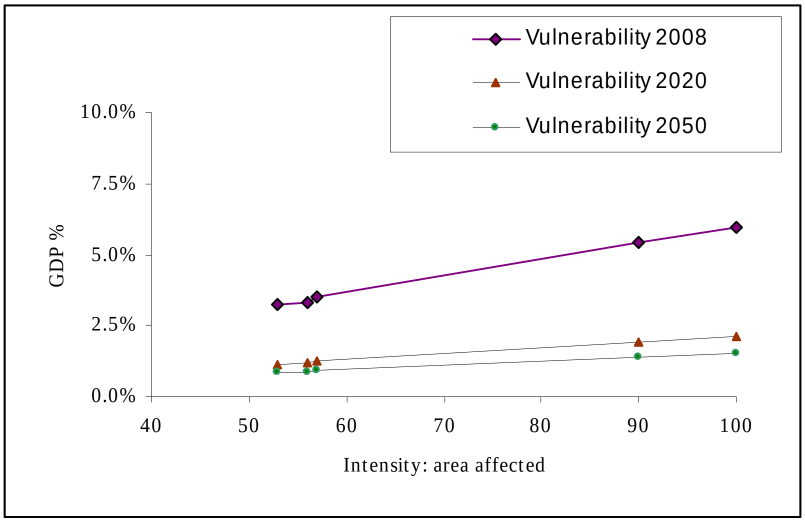


Fig. 11: Vulnerability curves for different years in terms of area affected and GDP losses.

It is assumed that the curves are linearly changing over the years and therefore the dynamic decrease of physical vulnerability as shown in the figure is approximated via simple linear estimations.

3.5 Findings 1: Direct Risk

This module combines the outputs of the three other modules to get an estimate of potential economic losses due to flood hazards and potential increases in the future. The flooded area is related to the losses via the physical vulnerability module, where for a given flooded area the relative losses can be determined, given the physical vulnerability for year t. Afterwards this value is combined with the exposure level, measured in GDP and this will result in the total loss for a given year. Because the hazard is described in probabilistic terms, losses are also probabilistic. In other words, the loss distribution is a function of the hazard and vulnerability as well as the exposure:

$$\tilde{L}_T = f(\tilde{F}_t, v_t)e_t$$

Under these settings figure 12 shows the relative asset losses expressed in terms of GDP for different years under the A2 SRES scenario.

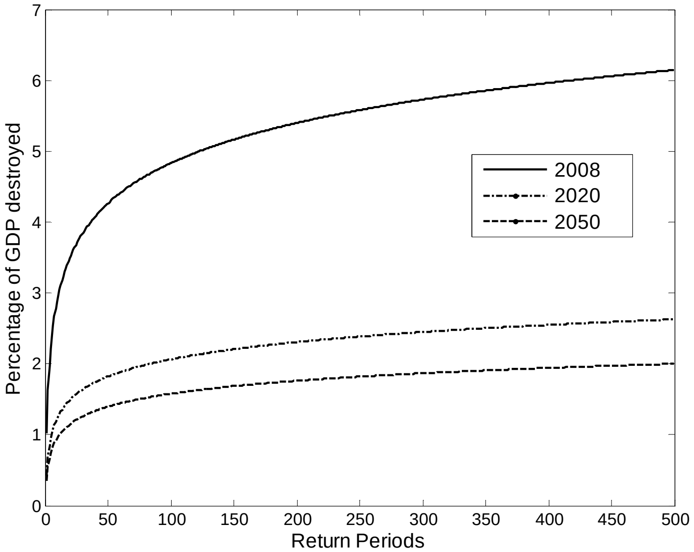


Fig. 12: Loss distribution for Bangladesh for today, 2020 and 2050

Interestingly, losses decrease sharply due to the (assumed) strong decrease in vulnerability in the future which overwhelms the increase of the hazard intensity over the whole time period.

4. Modeling economic risk

Section three presented our approach for dynamically assessing direct disaster risks now and in the medium term future based on GCM results as well as past hazard and loss data. To capture indirect risks the direct risk loss module is coupled with the CATSIM module which calculates risk measures over given time periods, e.g. 5 or 10 years. We now turn to explaining this integration.

4.1 The Economic Module

A key aspect of the CATSIM framework is the operationalization of economic resilience and vulnerability. Economic resilience relates to the general conditions of the economy and its agents and is independently analyzed of disaster risk. In CATSIM it is represented by the economic module. The macro-economic model is set out as a simple Solow-type growth framework and the model's focus is on the potential for medium to longer term growth and development of aggregate economic variables given the explicit consideration of disaster risks. The Solow model (more correctly Solow-Swan model) is considered the workhorse of economic growth research for studying the longer term potential development of an economy (see Barro and Sala-i- Martin, 2004 for a discussion of economic growth literature). In the simple exogenous savings version used here, economic growth is driven by the accumulation of capital via the savings-investment relationship and the rate of depreciation.[4] Economic vulnerability is understood as the susceptibility of the economic system to potential disaster damage (direct risk) and is determined by direct risk and economic resilience. Economic vulnerability may be determined by the following sets of elements.

- Financial Vulnerability: Availability of internal and external savings to spread risks so as to minimize those and refinance losses as well as increased post-disaster expenditure, e.g. for supporting the private sector with relief and recovery assistance.
- Economic redundancy: the ability to pool risks and geographical and economic diversification. This is being implemented via a Constant Elasticity of Substitution (CES) production function specification. A CES function has a more flexible form than the standard Cobb-Douglas-function as it allows inputs to be either complements or substitutes and input factors are not automatically perfectly substitutable. Thus, complementary production processes and bottlenecks occurring if one of the outputs (such as capital is reduced/destroyed) can be better analyzed (this specification has not been fully implemented as of the time of writing)

Our assessment for Bangladesh focuses on the former and studies the macroeconomic repercussions of disasters as a function of the availability of domestic and external savings for rebuilding lost assets and supporting the recovery of the economy. Using the information on direct risks and financial resilience, financial vulnerability can be evaluated. Financial vulnerability is defined as the lack of access to domestic and foreign savings for financing reconstruction investment and relief post-disaster. The shortfall in financing is measured by the term *resource gap*. The term resource gap has been defined in the economic growth modeling literature as the difference between required investments in an economy and the actual available resources. The main policy recommendation consequently has been to fill this gap with foreign aid (Easterly 1999). In this report, this tradition is followed and the resource gap is understood as the lack of financial resources to restore assets lost due to natural disasters and continue with development as planned. The following chart illustrates the calculation of this metric for a hypothetical case. Table 7 shows possible instruments that can be used for financing the losses and post-disaster needs. This includes ex-ante and ex-post measures, e.g. measures used before the disaster happens and measures used after a disaster event.

---

[4] Modeling economic growth only as a function of capital stock and the availability of new investment into capital stock has to be regarded as a limitation of the model. Solow and others have shown in the 1950s that in advanced countries more than 50% of economic growth can be explained by productivity increases. This number may not be as large for developing countries, but suggests that a considerable amount of growth is not purely driven by the amount of capital but rather its quality (Dinwiddy and Teal 1996: 85). Also, today economic theory generally stresses the importance of incentives, the role of human and social capital and the importance of robust institutions for economic development (Meier 1995). On the other hand, it is generally acknowledged that capital investment plays a major role as a driver of economic growth.

Table 7: Public sector ex post and ex ante financing sources for relief and reconstruction

Type	Source	Considered in model
Ex-post sources		
Decreasing government expenditures	Diversion from budget	Yes
Raising government revenues	Taxation	-
Deficit financing *Domestic*	Central Bank credit	Yes
	Foreign reserves	-
	Domestic bonds and credit	Yes
Deficit financing *External*	International borrowing	Yes
	Outside support, e.g. from EU solidarity funds	Yes
Ex-ante sources		
	Insurance	Yes
	Reserve fund	Yes
	Contingent credit	Yes

The calculation of the resource gap can be illustrated as follows on Figure 13. Given losses due to a certain event, such as the 100 year event (losses of 4,000 currency units), the algorithm evaluates the sources for funding these losses. An implicit ordering of these sources is assumed according to the availability and marginal opportunity costs of the sources: grants would have the least costs associated as these are donations; thus they would be used first. Second, budget diversions could be used, then domestic credit, followed by borrowing from international institutions and the international markets (bonds). While in this illustration, a 100 year event could be financed, for a 200 year (losses of 10,000 currency units), there would be lack of (ex-post) sources and consequently a resource gap. It is the main objective of CATSIM to illustrate the costs and benefits of closing this resource gap with ex-ante measures.

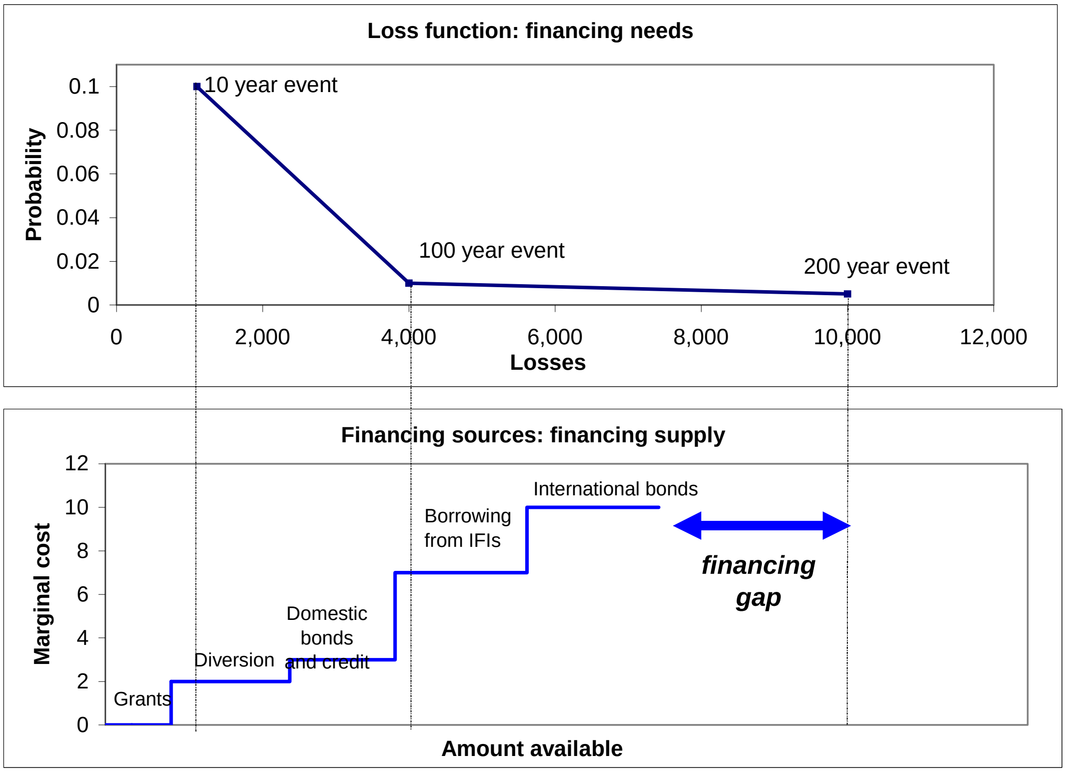


Fig. 13: Illustration for calculating the disaster resource gap

Based on the above discussion, CATSIM makes a number of important modifications to the Solow-type growth model:

- The main focus is on the public sector (national or state government), it fiscal liabilities and risk management strategies; the model is solved accordingly.
- Capital can be destroyed by natural disasters. As the occurrence of disasters is modelled stochastically, stocks and flows such as assets, budget and GDP become stochastic variables (labour is currently fixed).
- The private and public sector investment budget can be used for investing in new capital stock (or maintaining existing), replacing destroyed stocks or for protecting these assets by the ex-ante risk management measures mitigation or risk financing.
- There is a fixed government budget to be used for consumption and investment. Reconstruction of destroyed stocks has to be financed from the budget as well. Also debt service payments (e.g. due to incurring new debt for purposes of reconstruction) have to be paid from this budget.

Table 8: Overview over important model features of modeling approach

Model feature	**Description**
Assumed government objectives	Provide relief post-disaster and rebuild infrastructure quickly
GDP growth	Endogenous, GDP falls in year of event, in subsequent years GDP is determined by investment in previous year
Reconstruction investment	Government undertakes reconstruction investment for infrastructure, private sector undertakes reconstruction investment for private capital
Domestic savings	Limited supply, decrease after event, as income falls
Government consumption	Constant except for year of catastrophe
Private consumption	Constant, as low per capita income households increase their propensity to consume to maintain life-sustaining level of spending
Production function	Cobb-Douglas with inputs capital and labour
Treatment of capital	Catastrophe destroys capital
Treatment of labour	Labour force decreased in year of event
Imports and exports	Closed economy assumption

- Capital stock (private and public), labour and reserve fund are initialized.
- Capital stock can be destroyed by natural disasters. As the occurrence of disasters is modelled stochastically, stocks and flows produced by means of stocks become stochastic variables
- GDP is produced with the inputs labour and capital. Government revenue is a function of GDP.
- There is a fixed government budget to be used for consumption and investment. Reconstruction of destroyed stocks has to be financed from the budget as well. Also debt service payments (e.g. due to incurring new debt for purposes of reconstruction) have to be paid from this budget.
- The investment sub-budget can be used for investing in new capital stock (or maintaining existing) or for protecting these assets by the ex-ante risk management measures mitigation or risk financing. This is the major trade-off.

The purpose of the economic module has not been to develop estimates for main economic variables, but rather to contrast cases with and without additional ex-ante protection against natural disasters and study the effects over a certain time horizon. Currently, in order to represent the production of goods (supply) a Cobb-Douglas function is used with inputs capital and labour.

$$Y = k * L^{\alpha} K^{(1-\alpha)}$$

With k a technological efficiency parameter, L effective labour force, K capital stock, and alpha and beta representing the production elasticity's of capital stock and labour. Econometric models and time series (World Bank Indicators, 2007; Sanderson et al. 2008) starting from 1970 to 2005 are used for estimating the coefficients. Based on capital stock estimates, effective labour force and GDP values, least square regression is used, based on pre-analysis of the data, and gives a R square of 0.96, which seems reasonable estimates to be used. In the model capital stock can be destroyed and repaired each year due to the flood intensity and financial resilience of the country. However, the effective labour force is assumed here to be not affected through the disaster and is held constant over the year. The effects of disaster for the economy in the long run are explained in detail in the next section.

4.2. Macroeconomic Risk

As natural hazards are probabilistic in nature and therefore the losses due to such events are, the economic consequences on the long run have to be dealt within a probabilistic setting. To cover all possible disaster losses Monte-Carlo importance sampling simulation techniques are used, e.g. using the inverse distribution of the loss distribution and selecting only those scenarios where losses due to natural disasters occur. Furthermore, scenarios with more than one event within the considered time period are sampled using combinatorial results, e.g. looking at all possible scenarios where two or more events occurred within the time horizon. The probability of these different trajectories is calculated assuming a homogeneous Poisson distribution.

However, also the economy of the country and the financial resilience has to be modelled in a dynamic and probabilistic setting. For example, due to natural disaster events, the resilience could go down, which could result in higher financial vulnerability in the future against lower losses, then in other cases where no disaster event has happened in the past, or at a latter time. This situation is schematically shown in figure 14.

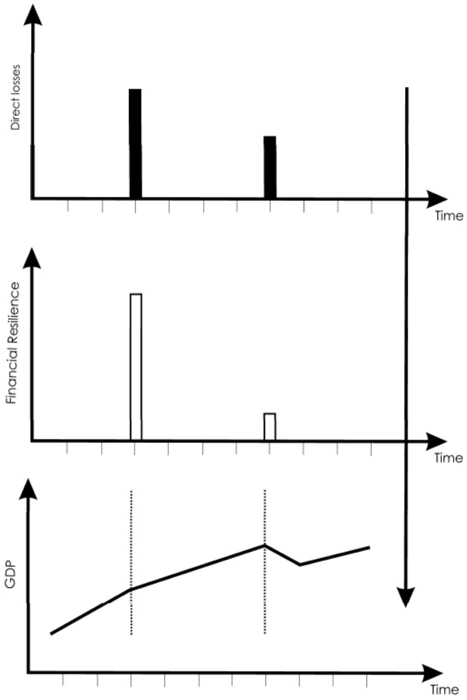


Fig. 14: Effects of Disaster in a macroeconomic setting.

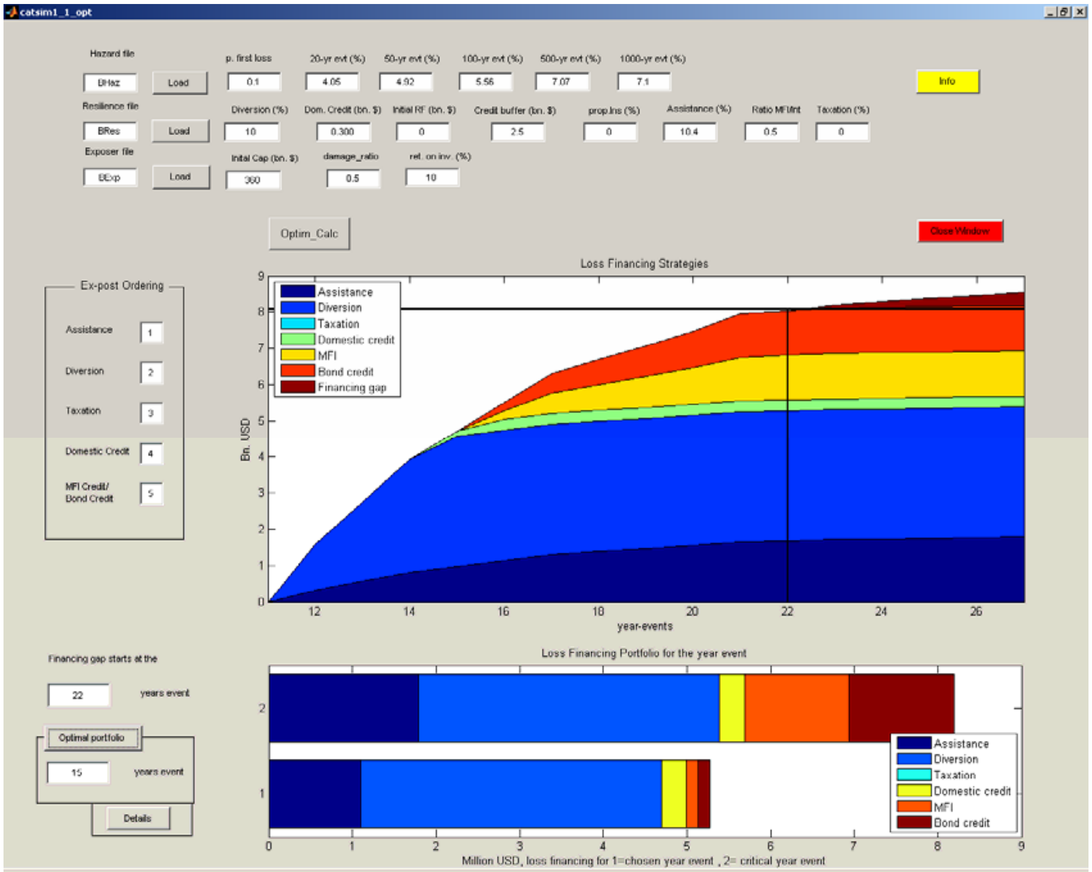
Hence, also the dynamic dependence has to be modelled and be based on the probability that such a possible future could occur. The probabilities of such scenarios are based on the probabilities of the events.

4.3 Capital Stock at Risk

For CATSIM total capital stock at risk is an important input parameter. Capital stock estimates were taken from Sanderson et al. (2009) based on the Penn World Tables and World Bank Indicators (2007). For example, 2005 capital stock is estimated to be 6.1 times GDP, which means that every unit of capital stock leads to a return of about 16% (decreasing after 1972 right after independence as the economy expands). This translates to approximately 360 billion USD (in constant 2000 prices) of capital stock for 2008. Least square regression for the parameters give an R square of 0.958, which seems to be a good fit.

4.4 Assessing financial vulnerability for Bangladesh

Based on a literature survey (see for example Benson and Clay (2002, 2005)), we assume that the following instruments can be used: (i) 10.4 percent of the total losses can be financed through outside assistance, e.g. through donors, part of that is also available for the government, (ii) a maximum of 10 percent from the government budget could be diverted for loss financing, (iii) a maximum of 300 million USD of domestic credits are possible, (iii) a maximum of 2.5 billion USD of foreign credit is available. With the direct loss estimates from section 3 one can calculate the resource gap year event for 2008, which is shown in figure 15.



Hazard file: BHaz
Resilience file: BRes
Exposer file: BExp
p. first loss: 0.1
20-yr evt (%): 4.05
50-yr evt (%): 4.92
100-yr evt (%): 5.56
500-yr evt (%): 7.07
1000-yr evt (%): 7.1
Diversion (%): 10
Dom. Credit (bn. $): 0.300
Initial RF (bn. $): 0
Credit buffer (bn. $): 2.5
prop.Ins (%): 0
Assistance (%): 10.4
Ratio MFI/Int: 0.5
Taxation (%): 0
Inital Cap (bn. $): 360
damage_ratio: 0.5
ret. on inv. (%): 10

Ex-post Ordering
Assistance: 1
Diversion: 2
Taxation: 3
Domestic Credit: 4
MFI Credit/ Bond Credit: 5

Financing gap starts at the 22 years event

15 years event

Fig. 15: Assessing financial vulnerability in Bangladesh using CATSIM.

As can be seen, Bangladesh seems currently to be financially very vulnerable to floods and other disasters, which is indicated through the low return period of the critical year event: A 22 year event, i.e. an event which on average happens every 22 years, will cause a resource gap. Based on this assessment and Monte Carlo simulation, possible scenarios of GDP paths can be estimated. Figure 16 shows scenarios for a time horizon of the 10 years from 2008 to 2017 for no event scenarios as well as for frequent and large event scenarios.

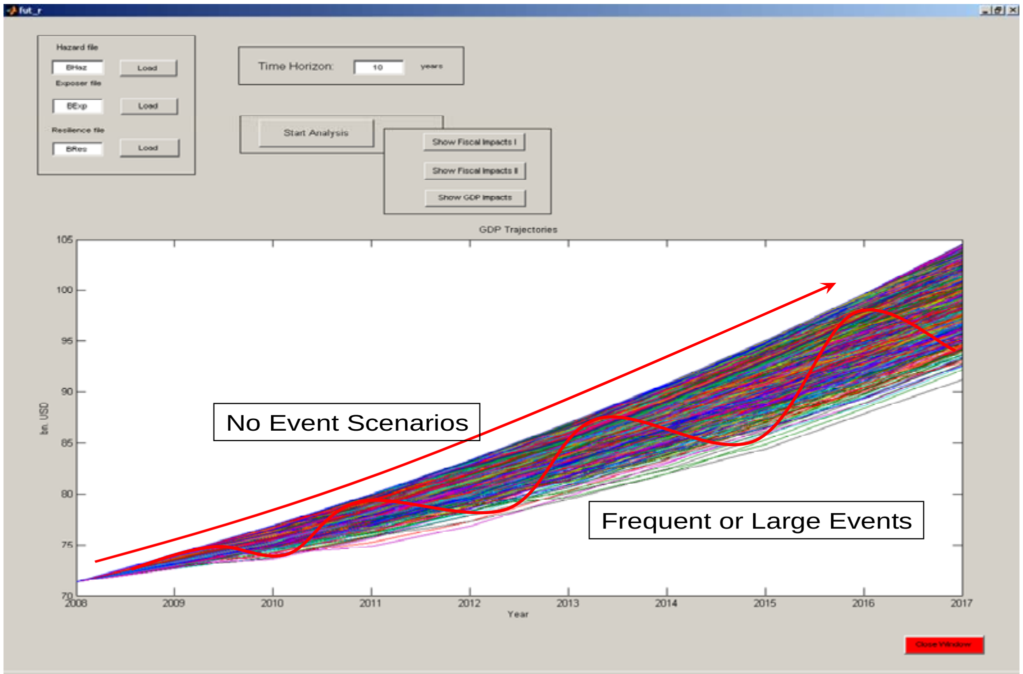

Hazard file: BHaz
Exposer file: BExp
Resilience file: BRes
Time Horizon: 10 years

Fig. 16: Comparison with no event and frequent or large events from 2008-2017

The macroeconomic model results have to be compared with past performance of the country due to natural disaster events. This is a quite tedious but inevitable part (see for example Benson and Clay, 2002, 2005). We used rough GDP estimates and projections in comparison with our loss distributions for the years with a catastrophe in Bangladesh to calibrate the model.

4.5 Findings 2: Economic risk

We compare our results in terms of GDP growth from 2008 to 2030 and 2050 with GDP as determined by the SRES A2 scenario. Furthermore, a comparison of the results where climate change or vulnerability change is held constant is made to see the contribution of those factors to the overall results (figure 17 and table 9).

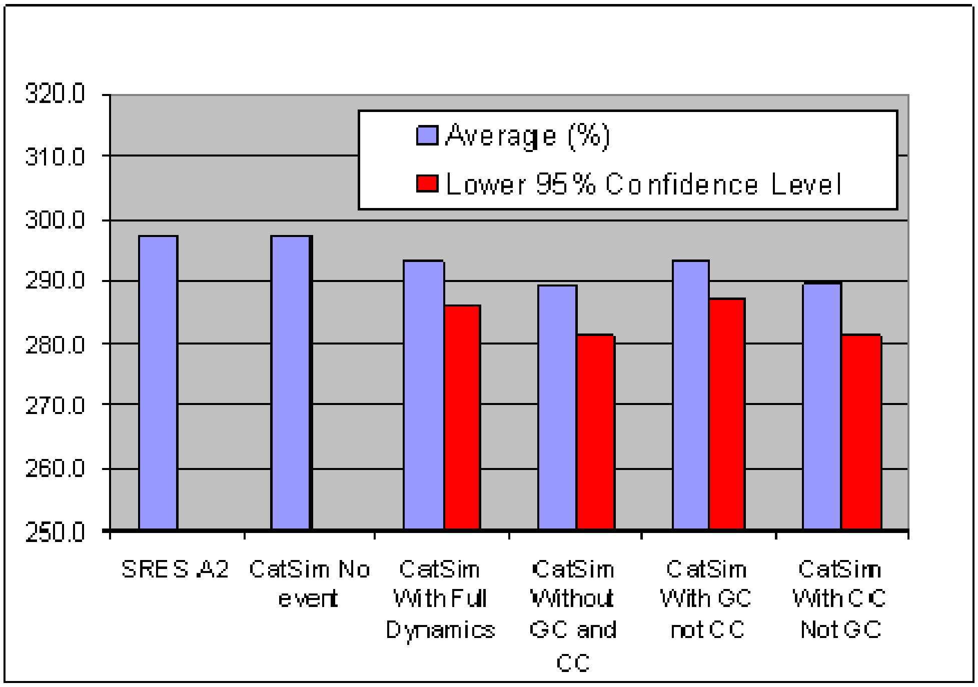


Fig. 17: GDP growth from 2008 to 2030 for different settings (in % of 2008)
Note: GC indicates global change, CC refers to climate change.

For 2030 the effects due to climate change are minor, while the effects of global change are important. However, the most important observation is the observed decrease of GDP due to the incorporation of disaster events. While the potential GDP increase from 2005 to 2030 is around 297 percent, it is for the full dynamic model (which was calibrated to the SRES A2 scenario), around 293 percent with a lower 95 percent interval of 286 percent. Observe that the reason for a not more drastic negative change is due to global change, i.e. decreased vulnerability.

Table 9: Results of different model runs for GDP in 2030 and 2050 (in % of 2008)

	In % compared to 2008	SRES A2	CATSIM No event	CATSIM With Full Dynamics	CATSIM Without GC and CC	CATSIM With GC not CC	CATSIM With CC Not GC
	Consideration of climatic and global drivers of risk		No events considered	Increase in hazard intensity and changing vulnerability	No reduction in physical vulnerability assumed, hazard kept constant	Reduction in physical vulnerability, hazard kept constant	Increase in the hazard considered, physical vulnerability as for the year 2008
2030	Average	297.3	297.3	293.0	289.2	293.0	289.4
	Lower 95% Confidence Level	-	-	286.0	281.2	286.9	281.4
2050	Average	783.0	783.0	774.8	763.6	774.8	763.8
	Lower 95% Confidence Level	-	-	761.6	742.0	761.5	741.9

Note: GC indicates global change, CC refers to climate change.

As in the case with 2030 also in 2050 a decrease compared to the SRES scenarios is observed. For both cases the global change component is more important than climate change, i.e. the increase in the magnitude of flood events is outweighed by the decrease in vulnerability. Furthermore, not taking account global change would lead to more pessimistic estimates than with, while not incorporating climate changes would yield less dramatic effects. The standard deviation in the case with climate change is higher, which means that outcomes due to climate change could be less dramatic than in the other cases without climate change impacts.

Estimating current and future extreme event risk (direct and economic) is fraught with high uncertainty. Particular important uncertainties relate to

- The recurrency of hazards: estimates are often based on a limited number of data points only.
- Incomplete damage assessments: data are often of limited reliability.
- Vulnerability: Information on vulnerability is often scarce, and important assumptions have to be made (such as done in this exercise on the strong decrease of vulnerability in the future in line with the decrease realized over the last few decades).
- For climate change, there are important uncertainties due to projecting changes in frequency and intensity of natural hazards as a function of changed weather patterns.

- Scenarios: the choice of a particular scenario, such as suggested by the SRES, importantly determines the risks to be estimated in terms of all of its drivers, i.e. hazard, exposure and vulnerability.

5. Conclusions

The approach presented in this paper aimed at incorporating both global and climatic change dynamics within a nationally-resolved economic growth framework in order to assess the importance of disasters and the global and climate-related drivers for medium-term development in Bangladesh. A key entry point for our analysis has been the fact that substantial progress has been made over the last few years in modeling extremes in a risk-based, more geographically explicit manner harnessing recent innovations and improvements in modeling techniques and data (for example, see Jones, 2004). Regional climate modeling and statistical downscaling methods, as well as climate and socio-economic downscaling techniques, which are more appropriate for analyzing localized extreme event patterns, can increasingly be made use of (Goodess et al., 2003). We would argue that it is important to apply these methods within a risk-analytic approach for assessing natural disaster risk as a convolution of geophysical signal, socioeconomic drivers and vulnerability that generate natural hazards via loss-frequency functions. Such a stochastic representation (with a discussion of parameter uncertainties) of extreme event risks more appropriately reflects the low-probability, high consequence nature of such events and its associated potential socio-economic impacts.

We focused on the economic dimensions of disaster risk and understood economic vulnerability as the susceptibility of the economic system to potential disaster damage (direct risk) and the ability to refinance the losses and “bounce back” from the event (termed here economic or indirect risk). The methodology was tested for Bangladesh and riverine flood risk, the major disaster type currently affecting Bangladesh. There are many caveats and uncertainties to be listed. Catastrophe model approaches deal with only a limited number of data points from the past and therefore, calibration as well as the estimation of important parameters, while based on scientific methods such as extreme value theory, are necessarily uncertain. Assumptions had to be made so that the operationalization of our model for a specific country case was feasible. Hence, while the projections into the future do not necessarily adequately represent a “real world” situation, the results have important and interesting implications.

There are many caveats and uncertainties to be listed. Catastrophe model approaches have to deal with only a limited number of data points from the past and therefore, calibration as well as the estimation of important parameters, while based on scientific methods such as extreme value theory, are necessarily uncertain. Furthermore, assumptions had to be made so that the operationalization of our model for a specific country case was feasible. Hence, while the projections into the future do not necessarily adequately represent a “real world” situation, the results have important and interesting implications.

First, we find global and climatic change to be important factors for determining future economic development and indirect risk. Similar to global IAM modelling, we find the global drivers to be more important than climate change drivers. We use similar increases of exposure in our model like Pielke and Sarewitz (2005), yet the key distinction of our approach is that we aim at incorporating physical and financial vulnerability explicitly in our modelling framework. As we find strong decreases in physical vulnerability and estimate financial vulnerability as the key transmission channel from direct to economic risks, we find the decreases in vulnerability to substantially reduce the worsening impacts due to increased flood hazard frequency and intensity in a warming climate and increased assets. Thus, while adaptation was only captured with roughly estimated physical and financial vulnerability functions due to the limited data available, the results show that this element is very important to consider. Second, while the assumption of decreasing vulnerability was made in this paper, it was also shown that without increasing adaptation capabilities the threat of natural hazards could increase largely due to the increase of the intensity of hazards. Third, the issue of increasing climate variability is not captured well due to the limitations of GCM projections and therefore is also limited here.

While it would be important to also consider those aspects, they would greatly complicate the process of calculating the various scenarios due to the large amount of samples needed to reflect all possible future situations in a representative manner. Hence, sampling techniques become increasingly important in order render calculations feasible within reasonable timeframes and computing capacities.

References

Barro, R.J. und Sala-I-Martin, X. (2004). Economic Growth, MIT Press, Cambridge.

Benson, C. (1997a). The Economic Impact of Natural Disasters in Fiji. Overseas Development Institute, London.

Benson, C. (1997b). The Economic Impact of Natural Disasters in Viet Nam. Overseas Development Institute, London.

Benson, C. (1997c). The Economic Impact of Natural Disasters in the Philippines. Overseas Development Institute, London.

Benson, C. and Clay, E. (2002). Bangladesh. Disasters and Public Finance. Disaster Risk Management Working Paper Series No. 6. The World Bank. Washington, D. C.

Brookshire, D. S., Thayer, M. A., Tschirhart, J., Schulze, W.D. (1985). A Test of the Expected Utility Model: Evidence From Earthquake Risks. Journal of Political Economy(93): 369-389

Brookshire, D. S., Chang, S. E., Chochrane, H., Olson, R. A., Rose, A., Steenson, J. (1997). Direct and Indirect Economic Losses from Earthquake Damage. Earthquake Spectra 13(November): 683-701

Burby, J. R. (1991). Sharing Environmental Risks: How to Control Governments losses in Natural Disasters. Westview Press, Boulder.

Chang, S., Rose, A., Shinozuka, M. (1997). Infrastructure Life Cycle Cost Analysis: Direct and Indirect User Costs of Natural Hazards. U.S.-Japan Joint Seminar on Civil Infrastructure Systems Research, August 28-30, 1997, Honolulu, Hawaii, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, State University of New York, Buffalo.

Cochrane, H. (1992). Overview of Economic Research on Earthquake Consequences. The Economic Consequences of a Catastrophic Earthquake: Proceedings of a Forum, The National Academy Press, Washington DC.

Dinwiddy, C. and Teal, F. (1996). Principles of Cost-Benefit Analysis For Developing Countries. Cambridge University Press, Cambridge.

Easterly, W. (1999). The Ghost of Financing Gap – Testing the Growth Model Used in the International Financial Institutions. Journal of Development Economics 60 (2): 424ff.

Ellson, R.W., Milliman, J. W., Roberts, R. B. (1984). Measuring the Regional Economic Effects of Earthquakes and Earthquake Predictions. Journal of Regional Science 24(4): 559-579

Fisher, S., and Easterly, W. (1990). The economics of the government budget constraint, The World Bank Research Observer 5 (2): 127-42

Freeman, P. K., L. A. Martin, J. Linnerooth-Bayer, R. Mechler, S. Saldana, K. Warner and Pflug, G. (2002a). Financing Reconstruction. Phase II Background Study for the Inter-American Development Bank Regional Policy Dialogue on National Systems for Comprehensive Disaster Management. Inter-American Development Bank, Washington DC.

Freeman, P. K., Martin, L., Mechler, R., Warner, K. with P. Hausman (2002b). Catastrophes and Development, Integrating Natural Catastrophes into Development Planning, Disaster Risk Management Working Paper Series No.4., The World Bank, Washington DC.

Goodess, C.M., C. Hanson, M. Hulme, and Osborn, T.J. (2003). Representing climate and extreme weather events in integrated assessment models: a review of existing methods and options for development. Integrated Assessment, 4, 145-171

Guimaraes, P., Hefner, F.L., Woodward, D. P. (1993). Wealth and Income Effects of Natural Disasters: An Econometric Analysis of Hurricane Hugo. Review of Regional Studies 23: 97-114.

Guy Carpenter in association with EQECAT with contributions from IIASA (2000). Managing the financial impacts of natural disaster losses in Mexico. Washington, DC. Mexico Country Office, Latin and Caribbean Region, The World Bank, Washington DC.

Hochrainer, S. (2006). Macreoeconomic risk management against natural disasters. Deutscher Universitaetsverlag (DUV), Wiesbaden.

Hochrainer, S. (2009). Assessing Macroeconomic Impacts of Natural Disasters: Are there any? Policy Research Working Paper 4968. Washington DC, The World Bank.

Hope, C. (2006). The marginal impact of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC's five reasons for concern. The Integrated Assessment Journal 6(1): 19-56

IPCC Working Group II (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability, Summary for Policymakers, Report approved at the Sixth Session of IPCC WGII, Geneva, Switzerland, 13-16 Feb.

IPCC (2007). Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability Summary for Policymakers. IPCC: Geneva.

Jones, R.N. (2004). Managing Climate Change Risks. In: Agrawal, S. and Corfee-Morlot, J. (eds.). The Benefits of Climate Change Policies: Analytical and Framework Issues, OECD, Paris.

Kamps, C. (2005) New Estimates of Government Net Capital Stocks in 22 OECD Countries 1960–2001. IMF Staff Papers.

Kasperson, J. and Kasperson, R. (2001). Summary of International Workshop on “Vulnerability and Global Environmental Change.” 17-19 May 2001. Stockholm Environment Institute (SEI). Sweden.

Kelly, P.M. and Adger, W.N. (2000). Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation. Climatic Change, 47: 325-352

Mechler, R. (2004). Natural Disaster Risk Management and Financing Disaster Losses in Developing Countries. Verlag fuer Versicherungswissenschaft, Karlsruhe.

Mechler, R., J. Linnerooth-Bayer, S. Hochrainer, G. Pflug (2006). Assessing Financial Vulnerability and Coping Capacity: The IIASA CATSIM Model. In J. Birkmann (ed.). Measuring Vulnerability and Coping Capacity to Hazards of Natural Origin. Concepts and Methods. United Nations University Press, Tokyo.

Meier, G.M. (1995). Leading Issues in Economic Development. Oxford University Press, New York.

Nabath, M. (2005). Reinsurance and microfinance. in ADA Newsletter No. 7, Microinsurance: Improving risk management for the poor. Luxembourg.

Nakicenovic N, Alcamo J, Gruebler A, Riahi K, Roehrl RA, Rogner H-H, Victor N et al. (2000). Special Report on Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Nordhaus, W. and J. Boyer (2000). Warming the World: Economic Models of Global Warming. MIT Press: Cambridge, Mass.

Noy, I. (2009). The macroeconomic consequences of disasters. Journal of Development Economics 88 (2008): 221-231

Okuyama, Y. (2007). Economic Modeling for Disaster Impact Analysis: Past, Present, and Future, Economic Systems Research 19 (2), pp.115-124.

Otero, R. C. and R.Z. Marti (1995). The impacts of natural disasters on developing economies: implications for the international development and disaster community. In M. Munasinghe and C. Clarke (eds.). Disaster Prevention for Sustainable Development: Economic and Policy Issues. World Bank, Washington DC.

Parry, M.L., O.F. Canziani, J.P Palutikof, P.J. van der Linden, Hanson, C.E. (eds.) (2007). Climate change 2007: Impacts Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovermental Panel of Climate Change. Cambridge: Cambridge University Press.

Pielke Jr., R. A. and D. Sarewitz (2005). Bringing Society Back into the Climate Debate. Population and Environment 26(3): 255 - 268

Rose, A. and G.-S. Guha (2001). Computable general equilibrium modeling of electric utility lifeline losses from earthquakes. In S. Change and Y. Okuyama (eds.). Modeling the Spatial Economic Impacts of Natural Hazards. Springer, Heidelberg.

Rose, A., J. Benavides, et al. (1997). The regional economic impact of an earthquake: direct and indirect effects of electricity lifeline disruptions. Journal of Regional Science 37(3): 437-458

Rotmans, J., M. Hulme, and T.E. Downing (1994). Climate Change Implications for Europe: An application of the ESCAPE Model. Global Environmental Change 4, 97-124

Smit, B., I. Burton, R.J.T. Klein, and R. Street (1999). The Science of Adaptation: A Framework for Assessment. Mitigation and Adaptation Strategies for Global Change, 4(3-4): 199-213

Solomon, S., D. Qin, et al., Eds. (2007). Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA, Cambridge University Press, Cambridge.

Stern, N. (2007). The Economics of Climate Change. Cambridge University Press, Cambridge.

Tanner TM, Hassan A, Islam KMN, Conway, D, Mechler R, Ahmed AU, and Alam, M (2007). ORCHID: Piloting Climate Risk Screening in DFID Bangladesh. Detailed Research Report. Institute of Development Studies, University of Sussex, UK.

UNFCCC (2008). FCCC/CP/2007/6/Add.1. UNFCCC, Bonn.

UNISDR (United Nations International Strategy for Disaster Reduction) (2005). Hyogo Declaration. World Conference on Disaster Reduction, Kobe.

Wreford, A., M. Hulme, and N. Adger (2007). Strategic Assessment of the Impacts, Damage Costs, and Adaptation Costs of Climate Change in Europe. Working paper. Tyndall Centre for Climate Change Research and School of Environmental Sciences, UEA, Norwich.

Yezer, A. M. and C. B. Rubin (1987). The Local Economic Effects of Natural Disasters.