ORCHID: Piloting Climate Risk Screening in DFID Bangladesh

An Economic and Cost Benefit Analysis of Adaptation Options

Nabiul Islam[1] and Reinhard Mechler[2]

[1] Bangladesh Institute of Development Studies (BIDS), Dhaka

[2] International Institute of Applied Systems Analysis, Vienna

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SECTION 1: SUMMARY

This chapter discusses the appraisal of economic efficiency of selected adaptation options to extreme climate-related event risks of the DFID development assistance portfolio in Bangladesh via Cost-Benefit Analysis (CBA). The methodology developed was tested as a pilot study for selected intervention options within the DFID Bangladesh portfolio as part of the ORCHID project and should be understood as an exploration of the potential to conduct such analyses with available data and modelling techniques. Such an approach may inform the prioritization and implementation of efficient disaster risk management and climate adaptation ("no-regret") options that help with coping with current and future extreme events as possibly increased in intensity and/or frequency by climate change.

Economic risk and the economic efficiency of selected adaptation options of the DFID development assistance portfolio in Bangladesh is estimated by means of Cost-Benefit Analysis (CBA) accounting for uncertainty and dynamic driving forces of hazards, vulnerability and exposure. A key concept employed in this analysis is the probabilistic representation of costs and benefits of risk reduction through the use of loss-frequency functions.

Although, for the Bangladesh case the data situation is good as concerns data on disaster impacts and risk, estimating extreme event risk and the benefits of risk reduction is fraught with substantial uncertainty, particularly so in this case, as disasters by definition are low-frequency, high consequence events. Uncertainties are among others associated with estimates of hazard and changes thereof, for example due to climate change, exposure of assets and people, fragility (the degree of damage for a given level of hazard intensity), the benefits of risk reduction, the proper choice of the discount rate and different cost concepts used for valuing impacts. In this assessment, due to data limitations and the scope of the study, it was not possible to conduct a quantitative uncertainty analysis (for example using confidence intervals); rather, sensitivity analysis was used to vary costs and benefits of options as well as the discount rate. The sensitivity of results to assumptions of those parameters and variables (as often in CBAs) was found to be considerable.

In order to set the stage for the CBA analysis and specific adaptation options, aggregate risk of flooding for economic asset risk for all of Bangladesh for now, in 2020 and 2050 under possible climate change is conducted. Economic assets losses today are estimated to amount to 0.6% when measured as a ratio of GDP, with a 50 year event (an event with an annual recurrency probability of 2%) possibly consuming about 5.8% of GDP. In the future, based on estimations of increasing frequency of flooding in Bangladesh due to climate change these losses may increase or decrease depending on the amount of adaptation assumed. If no adaptation is assumed (as is standardly done in similar assessments in the literature), annual average losses could increase to 0.7% and 0.75% of GDP in 2020 and 2050 (50 year events: 7.0 and 7.3% GDP). If significant adaptation as in the past, when, for example, loss of life per event in Bangladesh was reduced by two orders of magnitude over a 30 year period, is assumed, annual losses would decrease to 0.5 and 0.2% of GDP for 2020 and 2050 (50 year events: 4.6 and 1.9%). Uncertainty around these estimates and the assumptions utilized, while hard to quantify, is considerable and should be kept in mind. Accordingly, numbers should be understood in terms of orders of magnitude.

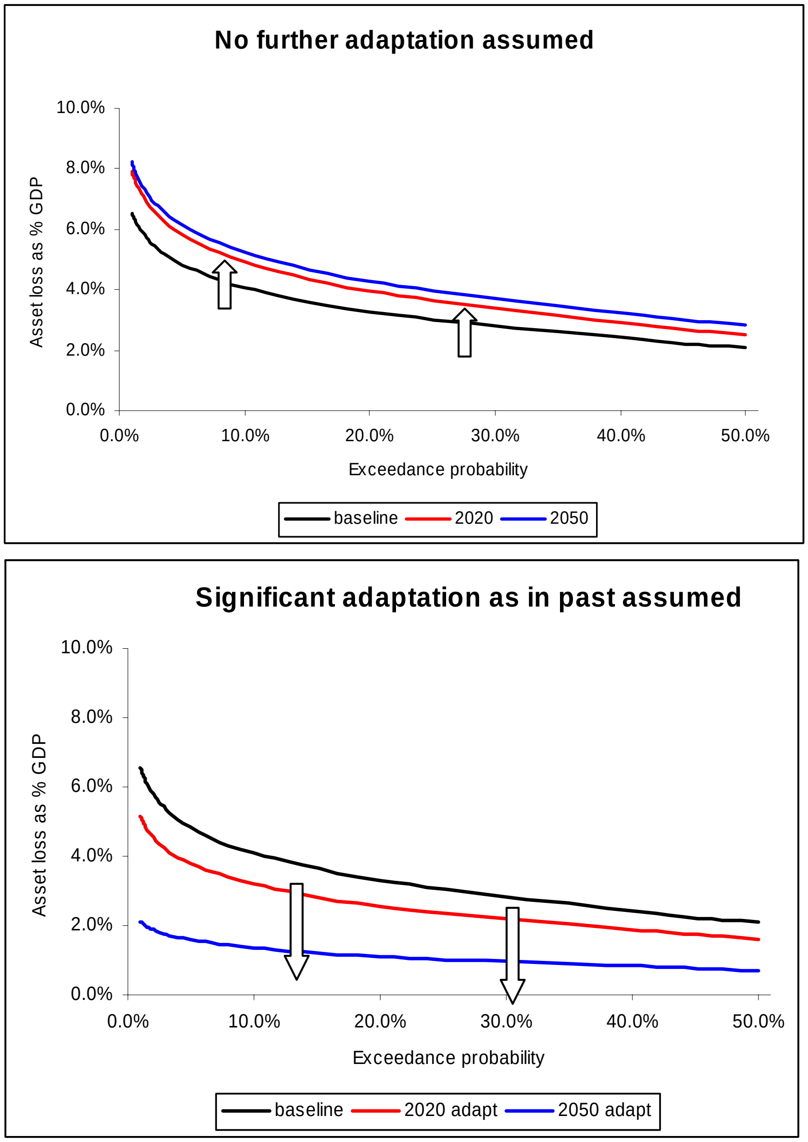

Fig. 1: Figure: Asset losses for the baseline, 2020 and 2050 without and with significant adaptation assumed

These estimates indicate the importance of adaptation (and assumptions on it) for thinking about climate change and climate change policy. The representation of adaptation in this top-down assessment of necessity is broad-brushed, locale-unspecific and based on adaptation that occurred in the recent past. A key question for this assessment and the adaptation discussion in general (for example see Stern, 2007) is the scope for such adaptation and whether it will occur autonomously or in a planned manner. In order to shed more light on these crucial issues, CBAs for two specific ongoing and planned adaptation options within the DFID-Bangladesh portfolio are analyzed in a more risk-based, bottom-up approach.

One option considered is the flood-proofing of roads and highways by raising this infrastructure above the highest ever-recorded flood levels within the DFID-sponsored programme “Roads and Highways Policy Management, budgetary and TA Support” (RHD). Specifically, some 170 Km of national and regional roads and some 518 Km of district (feeder) roads in high risk areas will be raised by 1m. Further, about 124km of national and regional roads in low risk area will be raised by 0.5m. As the option comprises a long-term programme and since the costs would be very high if incurred at one time, it proposes action when a particular road is due for major maintenance or re-surfacing, with priority given to high risk areas.

In the CBA calculations, it is assumed that costs and benefits are evenly spread over time, i.e. every year a constant amount is spent for flood-proofing, resulting in a gradual building-up of flood protection. Benefits considered are the avoided costs of reconstructing lost infrastructural asset (direct losses). Although an option with national scope, specific fragility and risk functions are employed for estimating risk and risk reduced. Furthermore, increases in hazard frequency as determined in the climate science inputs to the ORCHID screening process are studied and are taken to increase risk by 2.6% per annum.

Although very costly and an option with national coverage, the flood-proofing of RHD investments seems to be efficient given the assumptions taken. For such a *best estimate* case, a range in the benefit-cost ratio of 1.2-2.7 is calculated; thus, for this set of assumptions, the option would be (socially) beneficial. It would mostly still be larger than 1 with more pessimistic assumptions such as costs increasing by 50%. If however, under very pessimistic assumptions, costs are increased and benefits are supposed to be decreased by 50%, then for all discount rates considered the option would not be efficient anymore. This exemplifies the need for varying input parameters and studying the sensitivity of results given a lack of more comprehensive data.

The second option considered involves flood proofing individual homesteads against a maximum of 20 year floods on riverine islands, known as Chars. The option, which is already under implementation, is to construct earth platforms on beneficiaries land for the unit of a bari (homestead with 4 households). The riverine areas of Bangladesh are home to the poorest and most vulnerable communities in the country with over 80 percent living in extreme poverty. Inhabitants of these areas live under serious risk of frequent flooding. The option presented here considers raising the level of multiple areas, each large enough to accommodate four dwellings, a hand tube well and a toilet.

Such flood proofing reflects traditional practices in Bangladesh, including building houses on higher ground and the raising of public infrastructure such as roads, shared areas and water supply/sanitation facilities above experienced flood level. Not all households have the resources to do this, especially in the unprotected Char areas near the major river channels and donor support is required. The implementation involves paying for local labour to construct an earth platform for dwellings, buildings and the associated facilities on raised ground. The level to which the land is raised is currently based on the maximum observed flood levels (up to a 20-year flood), but the cost benefit analysis option analysed here also considers the effects of global sea level rise due to climate change.

This homestead raising option can be divided into two sub-options depending on whether or not the community will bear any costs associated with this. Under suboption A, the CLP project will raise one common platform for 4 dwellings, each with 150 M^2 area and will reconstruct individual houses. Other infrastructure provision such as tube wells and sanitation will also be constructed by the project. Under suboption B, the project will only raise the common platform while the beneficiaries will reconstruct their individual houses, including making other infrastructure provision such as tube wells and sanitation. The analysis is carried out for both cases.

Similar results as for the RHD option are obtained with slightly higher B-C ratios. For the best estimate cases, suboptions A and B seem to be beneficial given the assumptions taken; option B scores higher, as costs for the project are reduced by residents helping out. If more pessimistic assumptions on costs and benefits are taken, the suboptions eventually become inefficient with rising discount rates.

SECTION 2: CBA FOR CLIMATE AND DISASTER RISK

This chapter discusses the appraisal of economic efficiency of selected adaptation options to extreme climate-related event risks of the DFID development assistance portfolio in Bangladesh via Cost-Benefit Analysis (CBA). The methodology developed was tested as a pilot study for selected intervention options within the DFID Bangladesh portfolio as part of the ORCHID project. Such an approach may inform the prioritization and implementation of cost-effective disaster risk management and climate adaptation ("no-regrets") options that help with coping with current and future extreme events as possibly increased in intensity and/or frequency by climate change. The approach draws on prior work on CBA for disaster risk management (Mechler, 2005) and research on estimating flood risk and damage functions for Bangladesh (Islam, 2005, 2006).

2.1 Essentials of CBA

CBA is the main technique used by governments and public authorities for appraising public investment projects and policies. CBA has its origins in the rate-of return assessment/financial appraisal methods undertaken in business operations to assess whether investments are profitable or not. CBA takes a broader perspective and aims at estimating the overall "profit" for society. Generally, it is used to organise and present the costs and benefits, and inherent tradeoffs, and finally estimate the economic efficiency of projects.

There are several limitations to CBA that must be taken into account. One important issue is the lack of accounting for the distribution of benefits and costs in CBA.[1] CBA takes an utilitarian approach holding that social welfare is derived at by aggregating individual welfare and changes therein due to projects and policies. A focus on maximizing welfare, rather than its distribution is a consequence (Dasgupta and Pearce, 1978).[2] The CBA methodology adds together the monetized preferences of those who view themselves as "winners "with those that view themselves as "losers", but actual compensation is not required. If preferences are measured through market prices or "willingness to pay", it should be kept in mind that more weight is given to those with higher ability to pay. Moreover, CBA cannot resolve strong differences in value judgements that are often present in controversial projects (for example, nuclear power, bio-technology, river management, etc.).

Another difficulty is the assessment of non-market values such as for health and the environment. Although methods exist, this often involves making difficult ethical decisions, particularly regarding the value of human life for which CBA should be used with caution. Another important issue is the question of discounting. Applying high discount rates expresses a strong preference for the present while potentially shifting large burdens to future generations. However, when keeping these limitations in mind, CBA can be a useful tool and its main strength is its explicit and rigorous accounting of those gains and losses that can be effectively monetized, and in so doing, making decisions more transparent. CBA provides a common yardstick with a money metric against which to measure projects (Kopp et al., 1997). CBA and economic efficiency considerations should not be sole

[1] The general principle underlying CBA is the Kaldor-Hicks-Criterion, which holds that those benefiting from a specific project or policy should potentially be able to compensate those that are disadvantaged by it (Dasgupta and Pearce, 1978). Whether compensation is actually done, however, is often not of importance. Also, methods to account for the distribution of costs and benefits have been proposed, but are not used in practice (Little and Mirrlees, 1990).

[2] Also, no definite aggregation rule exists for aggregating individual preferences to a social welfare function. As Arrow (1963) has shown in the *Impossibility theorem* no such welfare function exists that allows the social ranking of alternative social states from individual preferences given that intuitively plausible criteria of social choice are satisfied. This is a serious restriction to CBA, as a main proposition contends that individual preferences should count in an assessment of social choice. The way out of this impasse usually taken is to introduce normative judgment by means of postulating a decisionmaker or observer that seeks to maximize social welfare. This can be the government, a project evaluator or a representative agent (see Dasgupta and Pearce, 1978).

criterion for evaluating policies and need to be integrated within a wider decision-making framework incorporating social, economic and cultural considerations.

While CBA's main function is to inform the actual project appraisal stage, it is of importance for the other phases of a project cycle, specifically the project identification and specification stage (preproject appraisal stage), where it can help to preselect potential projects and reject others. Also, in the evaluation phase, CBA is regularly used for assessing if a project really has added value to society. Though there are different levels of detail and complexity to CBA, the general features and principles of CBA are listed in box 1.

Box 1: Main principles of CBA

- **Revealed vs. expressed preferences:** In the revealed preference-approach, available market prices for goods (such as used for reconstructing a building) are used; in the expressed preference approach the value of a non-marketed good, such as the value of flood protection, is directly elicited.
- **With-and without-approach:** CBA compares the situation with and without the project/investment, not the situation before and after.
- **Focus on selection of "best-option":** CBA is used to single out the best option rather than calculating the desirability to undertake a project per se.
- **Societal point of view:** CBA takes a social welfare approach. The benefits to society have to outweigh the costs in order to make a project desirable. The question addressed is whether a specific project or policy adds value to all of society, not to a few individuals or business.
- **Clear define boundaries of analysis:** Count only losses within the geographical boundaries in the specified community/area/region/country defined at the outset. Impacts or offsets outside these geographical boundaries should not be considered.

2.2 Application to Disaster Risk Management

The main application of CBA in the context of disaster risk discussed here is using it for evaluating disaster risk management (DRM) projects. This application is extended in this analysis to climate change adaptation, which shares many of the characteristics of DRM (for example, see Sperling and Szekely, 2005). Key elements of the process are shown in figure 1.

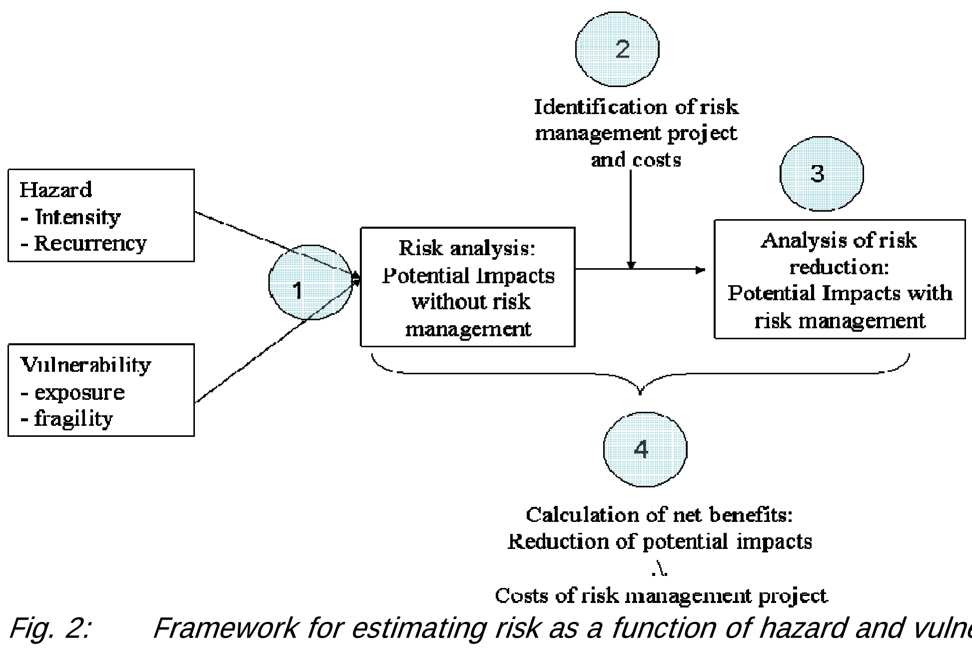

Fig. 2: Framework for estimating risk as a function of hazard and vulnerability

1. *Risk analysis:* risk in terms of potential impacts without risk management has to be estimated. This entails estimating and combining hazard(s) and vulnerability. The changing hazard burden due to the impacts of global climate change is estimated from best available science, noting the levels of certainty attached to projected changes.
2. *Identification of risk management measures and associated costs:* based on the assessment of risk, potential risk management projects and alternatives can be identified. The costs in a CBA are the specific costs of conducting a project, which consist of investment and maintenance costs. There are the financial costs, the monetary amount that has to be spent for the project. However of more interest are the so-called opportunity costs which are the benefits foregone from not being able to use these funds for other important objectives.
3. *Analysis of benefits risk reduction:* next, the benefits of reducing risk are estimated. Whereas in a conventional CBA of investment projects, the benefits are the additional outcomes generated by the project compared to the situation without the project, in this case benefits arise due to the savings in terms of avoided direct, indirect and macroeconomic costs as well as due to the reduction in variability of project outcomes. Only those costs and benefits that can be measured likewise are included. Often, an attempt is made to monetarise costs or benefits that are not given in such a metric, such as loss of life, environmental impacts etc. However, as the case with CBA generally, some effects and benefits will be left out of the analysis due to estimation problems. Generally, *revealed vs. expressed preference* approaches can be distinguished (Parker et al., 1987). In the revealed preference-approach, available market prices for goods, such as used for reconstructing a damaged building, are used; in practice, this involves adding up potential avoided impacts in terms of reconstruction costs. Alternatively, in the expressed preference approach, the value of a non-marketed good, such as the value of flood protection, is directly elicited by asking the potentially affected. The revealed preference approach is more common and followed for disaster risk management due to the general availability of some data, while for the revealed preference method, specific surveys would be required.
4. *Calculation of economic efficiency:* Finally, economic efficiency is assessed by comparing benefits and costs. Costs and benefits arising over time need to be discounted to render current and future effects comparable. From an economic point of view, 1 $ today has more value than 1 $ in 10 years, thus future values need to be discounted by a discount rate representing the preference for the present over the future. Last, costs and benefits are compared under a common economic efficiency decision criterion to assess whether benefits exceed costs. Basically, three decision criteria are of major importance in CBA:
   - Net present value (NPV): costs and benefits arising over time are discounted and the difference taken, which is the net discounted benefit in a given year. The sum of the net benefits is the NPV. A fixed discount rate is used to represent the opportunity costs of using the public funds for the given project. If the NPV is positive (benefits exceed costs), then a project is considered desirable.
   - The BC-Ratio is a variant of the NPV: The benefits are divided by the costs. If the ratio is larger than 1, i.e. benefits exceed costs, a project is considered to add value to society.
   - Internal Rate of return (IRR): Whereas the former two criteria use a fixed discount rate, this criterion calculates the interest rate internally, which represents the return of the given project. A project is rated desirable if this IRR surpasses the average return of public capital determined beforehand (eg. 12%).

   In most circumstances, the three methods are equivalent. In this assessment, due to its intuitive appeal, the BC-ratio will be used.

2.3 Assessing risk

A key issue in conducting CBA's in this context is the assessment of risk and impacts. Disaster risk is commonly defined as the probability of potential impacts affecting people, assets or the environment. Natural disasters may cause a variety of effects which are usually classified into social, economic, and environmental impacts as well as according to whether they are triggered directly by the event or occur over time as indirect or macroeconomic effects (fig. 2).

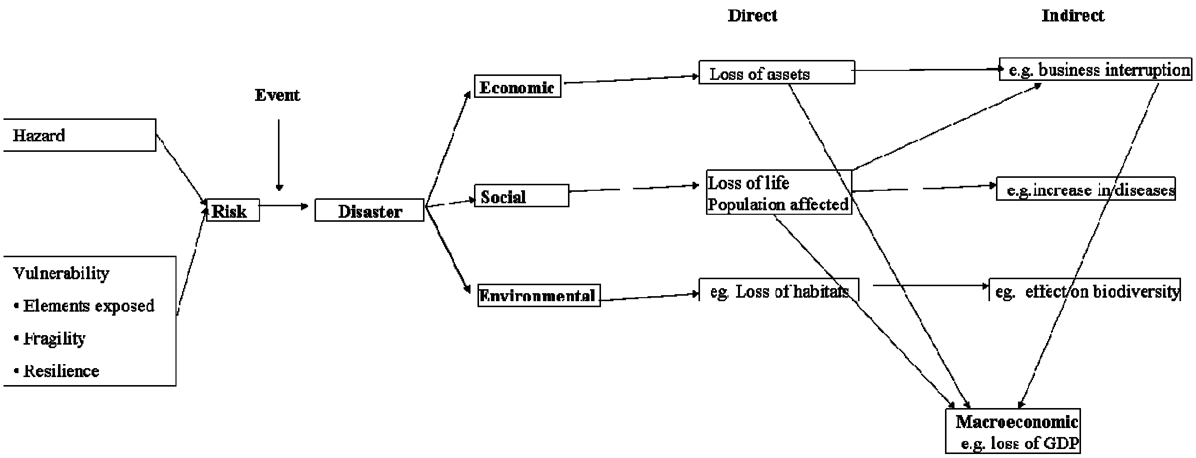

Fig. 3: Natural disaster risk and categories of potential disaster impacts

The standard approach for estimating natural disaster risk and potential impacts is to understand natural disaster risk as a function of hazard and vulnerability.[3] Hazard analysis involves determining the type of hazards affecting a certain area with specific intensity and recurrency. In order to assess vulnerability, the relevant elements (population, assets) exposed to hazard(s) in a given area need to be identified. Furthermore, the susceptibility to damage (in the following called vulnerability) of those elements associated with a certain hazard intensity and recurrency needs to be assessed. Resilience decreases vulnerability and is denoted as the ability to return to pre-disaster conditions; appropriate organisational structures, know-how of prevention, mitigation ands response have a decisive influence on resilience. Combining hazard and vulnerability, results in risk and potential effects to be expected. Risk management projects aim at reducing these effects. Benefits of risk management are the reduction in risk estimated by comparing the situation with and without risk management.

2.4 Assessing Impacts and potential benefits

Natural disasters and associated impacts are triggered by a specific event. Risk is commonly defined as the probability of a certain event and associated impacts occurring. Potentially, there are a large number of impacts, in actual practice however, only a limited amount of those can and is usually assessed. Table 1 presents the main indicators for which usually at least some data can be found.

[3] More and detailed information can be found in the *Risk analysis* guidelines published by the GTZ (GTZ, 2004).

Table 1: Summary of quantifiable disaster impacts equaling benefits in case of risk reduction

	Monetary		**Non-monetary**	
	Direct	**Indirect**	**Direct**	**Indirect**
Social Households			Number of casualties Number of injured Number affected	Increase of diseases Stress symptoms
Economic				
Private sector Households	Housing damaged or destroyed	Loss of wages, reduced purchasing power		Increase in poverty
Public sector Education Health Water and sewage Electricity Transport Emergency spending	Assets destroyed or damaged: buildings, roads, machinery, etc.	Loss of infrastructure services		
Economic Sectors Agriculture Industrv Commerce Services	Assets destroyed or damaged: buildings, machinery, crops etc.	Losses due to reduced production		
Environmental			Loss of natural habitats	Effects on biodiversity
Total				

The list is structured around the 3 broad categories of social, economic and environmental indicators, whether the effects are direct or indirect and whether they are originally indicated in monetary or non-monetary terms:

- Direct: Due to direct contact with disaster, immediate effect.
- Indirect: Occur as a result of the direct impacts, medium-long term effect.
- Monetary: Impacts that have a market value and will be measured in monetary terms.
- Non-monetary: Non-market impacts, such as health impacts.

Economic impacts, the focus of this chapter, are usually grouped into three categories: direct, indirect, and macroeconomic effects (ECLAC, 2003). These effects fall into stock and flow effects: direct economic damages are mostly the immediate damages or destruction to assets or “stocks,” due to the event per se. The direct stock damages have indirect impacts on the “flow” of goods and services: Indirect economic losses occur as a consequence of physical destruction affecting households and firms. Assessing the macroeconomic impacts involves taking a different perspective and estimating the aggregate impacts on economic variables like gross domestic product (GDP), consumption and inflation due to the effects of disasters, as well as due to the reallocation of government resources to relief and reconstruction efforts. As the macroeconomic effects reflect indirect effects as well as the relief and restoration effort, these effects cannot simply be added to the direct and indirect effects without causing duplication, as they are partially accounted for by those already (ECLAC, 2003).

Care needs to be taken not to double-count when including direct and indirect impacts. Generally, good data are often only easily available for the direct monetary impacts. In the following, also information on indirect losses, such as income losses will be employed.

2.5 Frameworks for estimating risks and cost and benefits

Two frameworks for the estimation and monetary quantification of disaster risk for the purposes of a CBA are presented here:

- The more rigorous *risk-based* framework (forward-looking, risk-based) combining data on hazard and vulnerability (fragility and exposure) to an estimate of risk and risk reduced; and
- The more pragmatic *impact-based* framework relying on past damages (backward-looking, impact-based), focusing on past damages and modifying those to come to a first-order understanding of risk.

The appropriate approach to be used depends on the objectives of the specific CBA conducted, the data situation and available resources and expertise.

For Bangladesh and the assessment of the economic efficiency of selected DRR options under dynamic conditions including climate change via CBA these two frameworks were use to tackle the following issues

- The impact-based macro assessment of disaster risk and potential changes due to climate change on the national level. One crucial question here is the level of adaptation that can be assumed for the future.
- Risk-based CBAs of specific ongoing and planned DRR. These can help identify cost-effective DRM and adaptation options and set the stage for estimating national-level adaptation in the future.

For Bangladesh, when estimating risk for the whole country the impact-based approach is likely to be more applicable, while bottom-up assessment can be risk-based, using established damage functions for given hazards. Risk-based calculations combine given hazard probabilities with vulnerability factors derived from a combination of exposure and vulnerability. Exposure (people and assets at risk) are calculated as a function of GDP and/or population, with projected changes for the future. Fragility (degree of damage of the exposed people and assets) is more complex and proxies are therefore established based on damage functions, which are explained for flooding in detail in part 2 of this report. Changes in hazards in the future due to climate change have been estimated by climate scientists working on the project.

2.6 Uncertainty

Estimating extreme event risk and the benefits of risk reduction is fraught with a substantial amount of uncertainty, particularly so in this case, as disasters by definition are low-frequency, high consequence events. Uncertainties are inherent in

- The recurrency of hazards: estimates are often based on a limited number of data points only.
- Incomplete damage assessments: data will not be available for all relevant direct and indirect effects, particularly so for the non-monetary effects.
- Fragility: fragility curves do often not exist.
- Exposure: the dynamics of population increase and urban expansion, increase of welfare need to be accounted for.
- Benefits of risk management estimates: often difficult to accurately measure the effect and benefit of risk management measures.
- Discounting: the discount rate used reduces benefits over the lifetime of a project and thus has very important impact on the result.

- Valuation issues: exchange rates, deflators and different cost concepts (replacement, market values) used.
- Additionally for climate change, uncertainties are due to estimating the changes in frequency and intensity of natural hazards

For example, the following chart shows possible overestimation and underestimation biases when estimating risk by means of a loss-frequency distribution (chart 3).

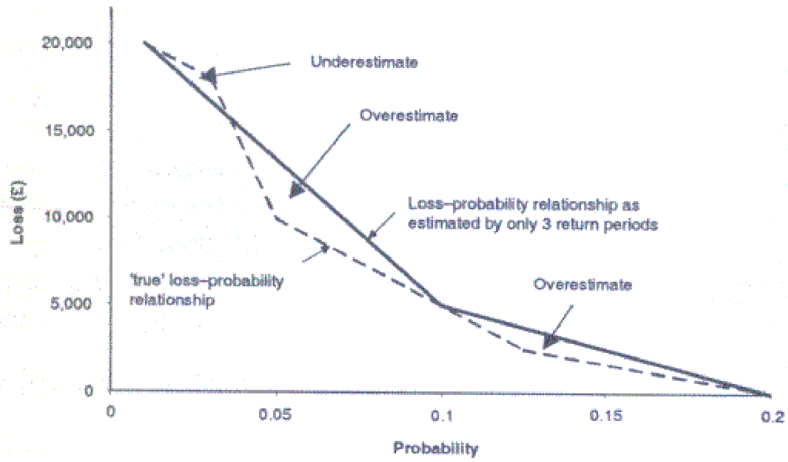

Fig. 4: Over- and estimation biases in estimating risk by means of loss-frequency distribution Source: Penning-Rowsell, 2000

When fitting the distribution by a limited number of data points (for example, in above figure 3 data points are available only), loss may be overestimated or underestimated relative to the “true” loss probability relationship. Of course, in practice the “true” relationship is never known. What the chart demonstrates is that with increasing data points, the approximation to the underlying relationship is bound to get better. However, as discussed (and further elaborated in the case studies) often the number of data points that can be derived is limited due to lack of data and time and money constraints. Estimates of risk and benefits of risk reduction should be understood in terms of orders of magnitude. The specific sources of uncertainty are discussed in more detail in the assessment of the adaptation options.

SECTION 3: BACKWARD-LOOKING APPROACH AND ASSESSING RISK

In a less rigorous and less data-intensive backward-looking assessment past damages build the basis for a rougher understanding of risk and potential damages.

1. Assessing relative losses and associated probabilities.
2. Adjust for dynamic driving forces of vulnerability and exposure.
3. Risk reduction and benefits thereof can be estimated (not done here for the aggregate risk exercise).

Such an assessment may be more applicable where damage functions are not developed (e.g. other than flood hazard) or the scale under investigation is too broad to use damage functions. This approach is illustrated in Figure 4 and was followed to assess current and future risk to economic assets all over Bangladesh.

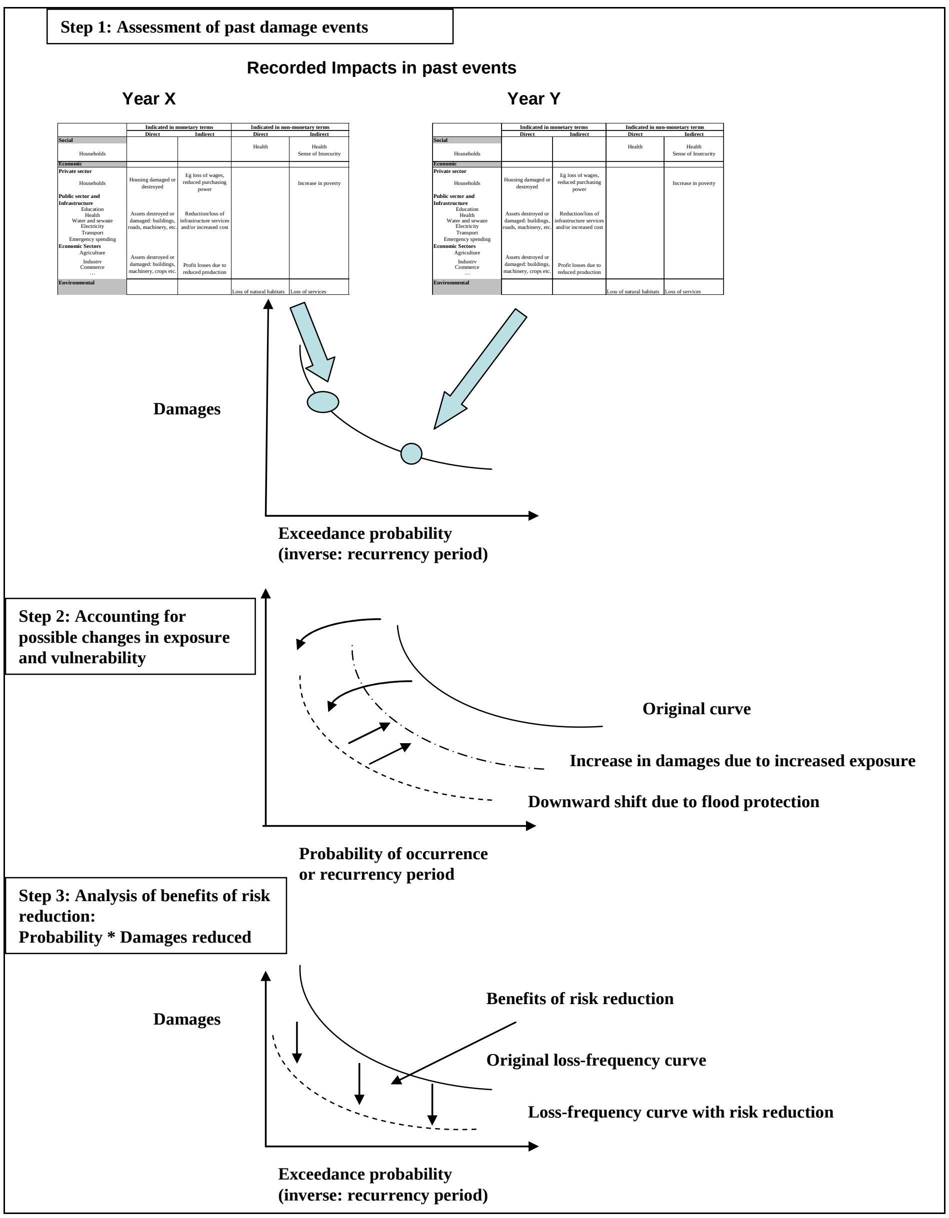

Fig. 5: Backward-looking assessment framework based on impacts

The following section outlines methodological steps and associated results for the analysis for the case of flooding in Bangladesh.

Step 1: Assessing relative losses and associated probabilities

First, 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. Generally, disaster statistics, as used in this case, list the direct economic losses in terms of impacts on physical structures such as roads, buildings and other assets.[4] The second to last column in table 2 shows those values in terms of GDP, and the last column tabulates return periods of events as estimated by Islam (2005). These direct impacts range from 2% of GDP for the 1984 flood (with a suggested return period of 2 years, i.e. a 2 year event) to 7.5% for the 1974 flood event, presumably a 9 year event.

Table 2: Selected impacts for worst floods in Bangladesh over the last 33 years

Year	Asset losses (million current US$)	Fatalities	Affected (million)	Affected country ('000 sq km)	Houses damaged ('000s)	GDP current (million US$)	**Asset losses as % GDP**	**Estimated return period (years) per Islam, 2005**
1998	2128	918	31	100	2647	44092	**4.8%**	**90**
1988	1424	2379	47	90	2880	26034	**5.5%**	**55**
1987	1167	1657	30	57	989	23969	**4.9%**	**13**
2004	1860	285	33	56	895	55900	**3.3%**	**12**
1974	936	28700	30	53	Na	12459	**7.5%**	**9**
1984	378	1200	30	Na	Na	19258	**2.0%**	**2**

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

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).

With probabilities of economic asset losses as a percentage of GDP in the year of the event, a so-called loss-frequency curve can be established. Adjustments need to be undertaken in order to arrive at a first-order representation of risk for today's (2007) conditions.

Step 2: Adjust for dynamic driving forces in the past

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 (eg due to climate change),
- Vulnerability may change as
    - Exposure may change due to higher asset concentration, population growth or migration, or/and

[4] Economists differentiate between economic assets (machinery, buildings, infrastructure) and flows (income, consumption), which are produced with inputs of assets and labour.

- 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 (2007) drawn. The result is a standard downward sloping loss-frequency curve (low probabilities of high consequences and vice versa).

Table 3: Deriving a representation of current risk for Bangladesh

Description	Economic risk in relative terms adjusted for asset exposure	Risk of loss of life adjusted for population exposure	Proxy for hazard and intensity	Economic risk adjusted for exposure and hazard	Risk of loss of life adjusted for exposure and hazard	Normalization to 2004	Economic risk adjusted for exposure and hazard	
Year	**% GDP**	Fatalities per population of 10 million	% area affected	rel losses/area affected	Fatalities per 10 million /area affected	Fragility adjustment factor	**Current risk: normalized to 2004**	Estimated return period (years) per Islam, 2005***
1998	**4.8%**	0.3%	68.0%	0.030	0.071	0.81	**6.0%**	90
1988	**5.5%**	0.5%	62.0%	0.051	0.088	1.01	**5.4%**	55
1987	**4.9%**	0.6%	40.0%	0.055	0.122	1.39	**3.5%**	13
2004**	**3.3%**	0.1%	38.0%	0.009	0.088	1.00	**3.3%**	12
1974	**7.5%**	9.6%	37.0%	0.957	0.203	2.32	**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 2007, as this is the last data point with impact data.
*** The return periods are estimated in relation to affected areas.

Figure 5 shows how the value of this proxy 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.

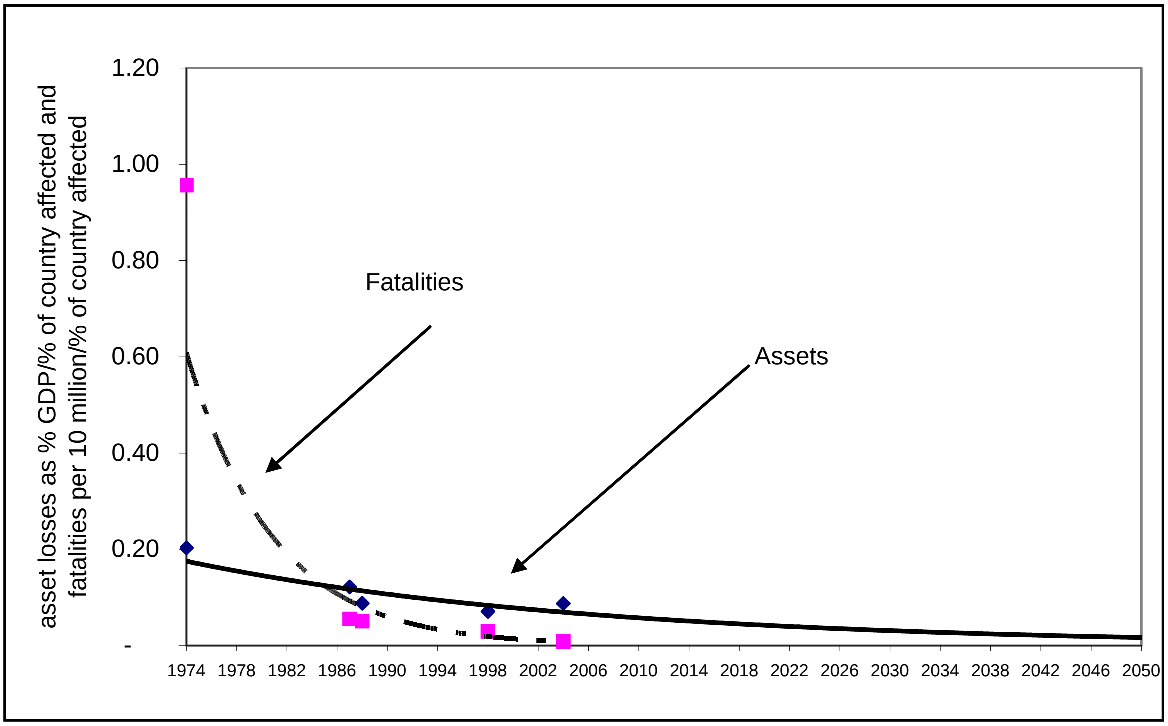

Fig. 6: Fragility proxies for assets and fatalities

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 6 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.

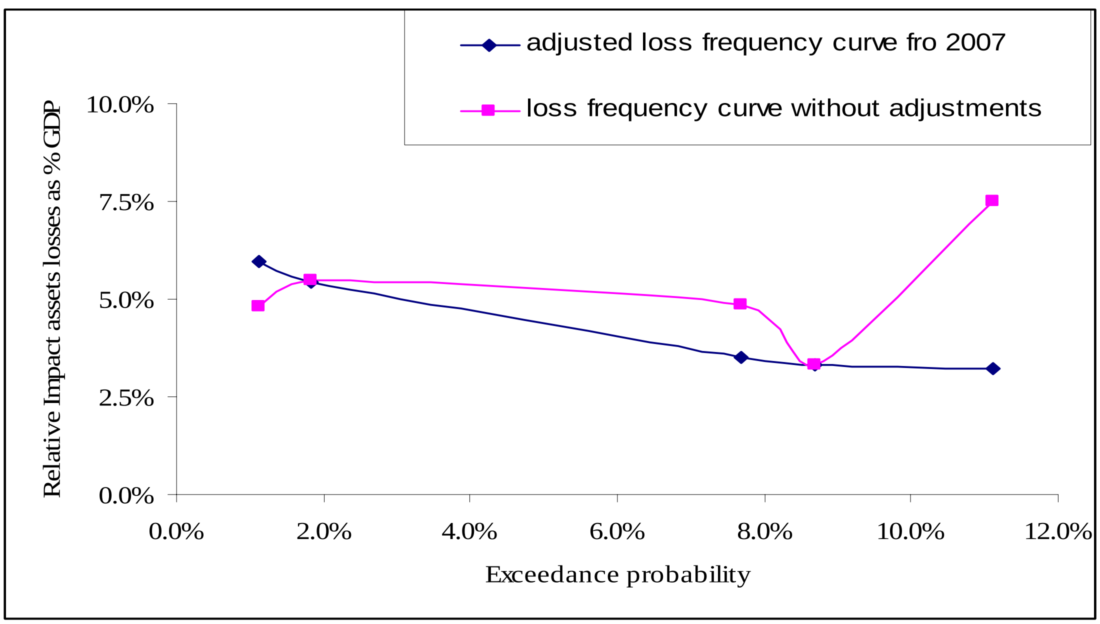

Fig. 7: Loss frequency curve for asset losses measured in terms of GDP in major floods events in Bangladesh

In order to account for changes in hazard frequency and/or intensity, the CBA draws on the results of the natural science components of this report presented in the climate science inputs to the ORCHID screening process for the IPCC b1 future greenhouse gas emissions scenarios in 2020 and 2050. Climate change is assumed to change frequencies of loss events due to its impact in terms of area affected. Given a lack of more detailed data, this economic analysis draws the assumption that economic impacts such as loss of assets would be proportional to area affected and thus frequencies can be adjusted likewise.

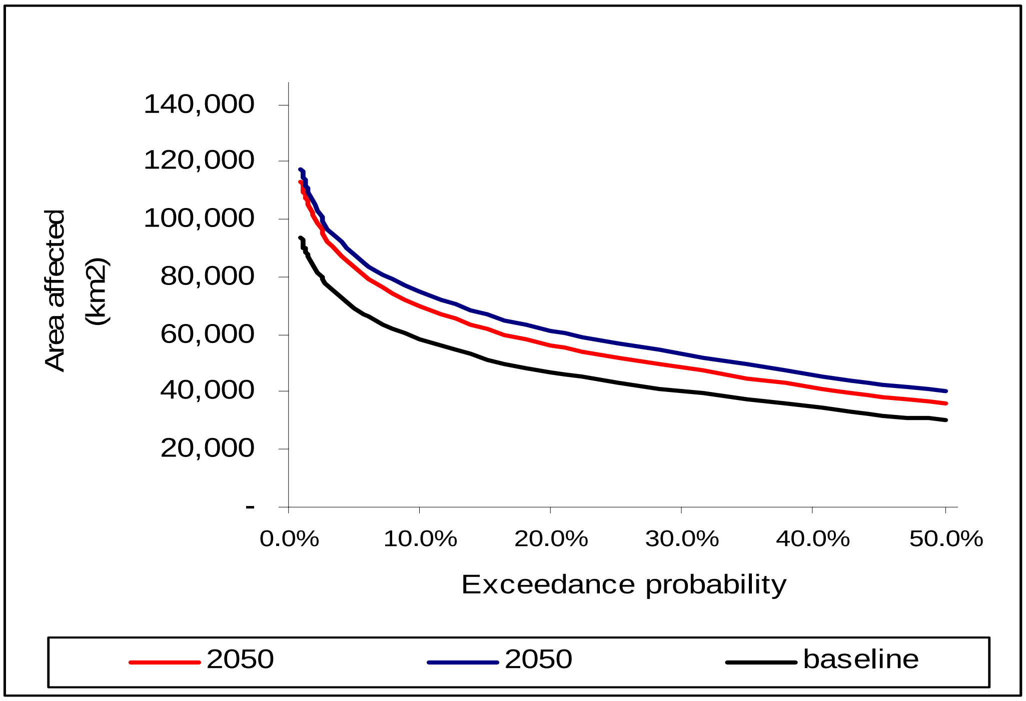

Fig. 8: Projected change in frequency of severe instances with areas flooded

Source: Hassan and Conway, Climate science inputs to ORCHID detailed research report

As well as changes to the burden of hazards in the future, changes in vulnerability also need to be represented. Two vulnerability and adaptation cases were considered.

- No adaptation case :

In this scenario, no additional adaptation beyond current efforts is assumed and thus with increased frequency of flooding, losses would increase. This scenario is unlikely given that some degree of adaptive adjustment can be expected as a response to increasing losses, but exemplifies a worst case.

- Significant adaptation case:

In the alternative scenario, significant adaptation is assumed and the relationship is extrapolated from data on successful reduction of losses in events in the past. The extrapolation is based on the asset fragility curve shown in figure 5 and conducted to 2020 and 2050. Due to the exponential fit, it is assumed that the fragility decreasing effect over the next 4 decades is substantial, which is a strong assumption. With such significant adaptation occurring, despite changing frequency of hazards, asset losses as a share of GDP would substantially be reduced.

The results in terms of asset risk for Bangladesh for the respective scenarios are shown in figures 8 a and b.

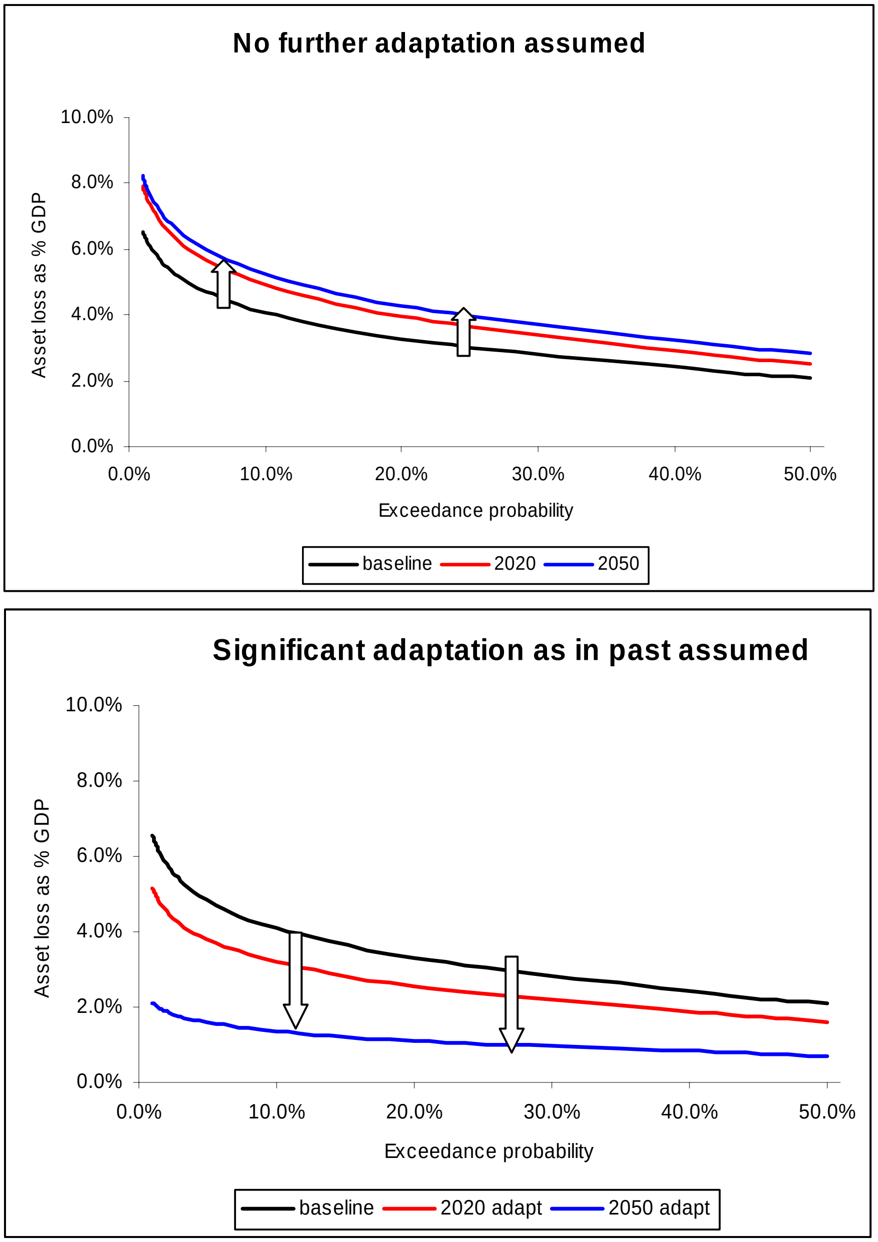

Fig. 9: a. and b.: Asset losses for baseline, 2020 and 2050 without and with significant adaptation assumed

Both adaptation scenarios are probably unrealistic and actual adaptation may lie somewhere in between these scenarios. For the baseline, economic assets losses today are estimated to amount to 0.6% of GDP with a 50 year event (an event with an annual recurrency probability of 2%) amounting to about 5.8% of GDP. In the future, based on estimations of increasing frequency of flooding in Bangladesh due to climate change these losses may increase or decrease depending on the amount of adaptation assumed. If no adaptation is assumed (as is standardly done in such assessments, e.g. Stern, 2007), annual average losses could increase to 0.7% and 0.75% of GDP in 2020 and 2050 (100 year events: 7.0 and 7.3% GDP). If significant adaptation is assumed based on past experience, where for example, loss to life per event was reduced by two orders of magnitude, is assumed, annual losses would decrease to 0.5 and 0.2% of GDP for 2020 and 2050 (50 year events: 4.6 and

1.9%). These broad-brushed estimates indicate the potential for reducing risk through adaptation in the context of future climate change.

Table 4: Losses for baseline, 2020 and 2050 with and without adaptation

	%	No further adaptation		Further adaptation assumed	
Return Period	Baseline	2020	2050	2020	2050
(T year)					
10	4.1%	4.9%	5.2%	3.2%	1.3%
50	5.8%	7.0%	7.3%	4.6%	1.9%
100	6.5%	7.9%	8.2%	5.1%	2.1%
Expected annual losses	**0.60%**	**0.7%**	**0.8%**	**0.5%**	**0.2%**

The representation of adaptation in this top-down assessment of necessity is broad-based, locale-unspecific and based on adaptation that occurred in the recent past. A key question for this assessment and the adaptation discussion in general (for example see Stern, 2007) is the scope for such adaptation and the extent to which it will occur autonomously or to which it will require specific planning and intervention . In order to shed more light on these crucial issues, in the following, CBAs for two specific ongoing and planned adaptation options within the DFID-Bangladesh portfolio are analyzed using a more risk-based, bottom-up approach.

SECTION 4: COST BENEFIT ANALYSIS USING A FORWARD-LOOKING FRAMEWORK

For measuring risk and the benefits arising due to selected adaptation or risk reduction options in a risk-based framework 4 steps are followed as illustrated in Figure 9. The first three steps correspond to calculating the hazard and vulnerability profiles to inform a risk assessment. Based on this, in a fourth step the benefits due to risk reduction can be determined. In detail, the necessary steps are:

1. Hazard analysis: Identifying intensity and frequency of the respective hazard(s) and changes therein, for example due to climate change,
2. Vulnerability analysis: Assessing exposure and fragility,
3. Risk analysis: combining hazard and vulnerability to an estimate of risk, and
4. Analysis of the benefits of risk management.

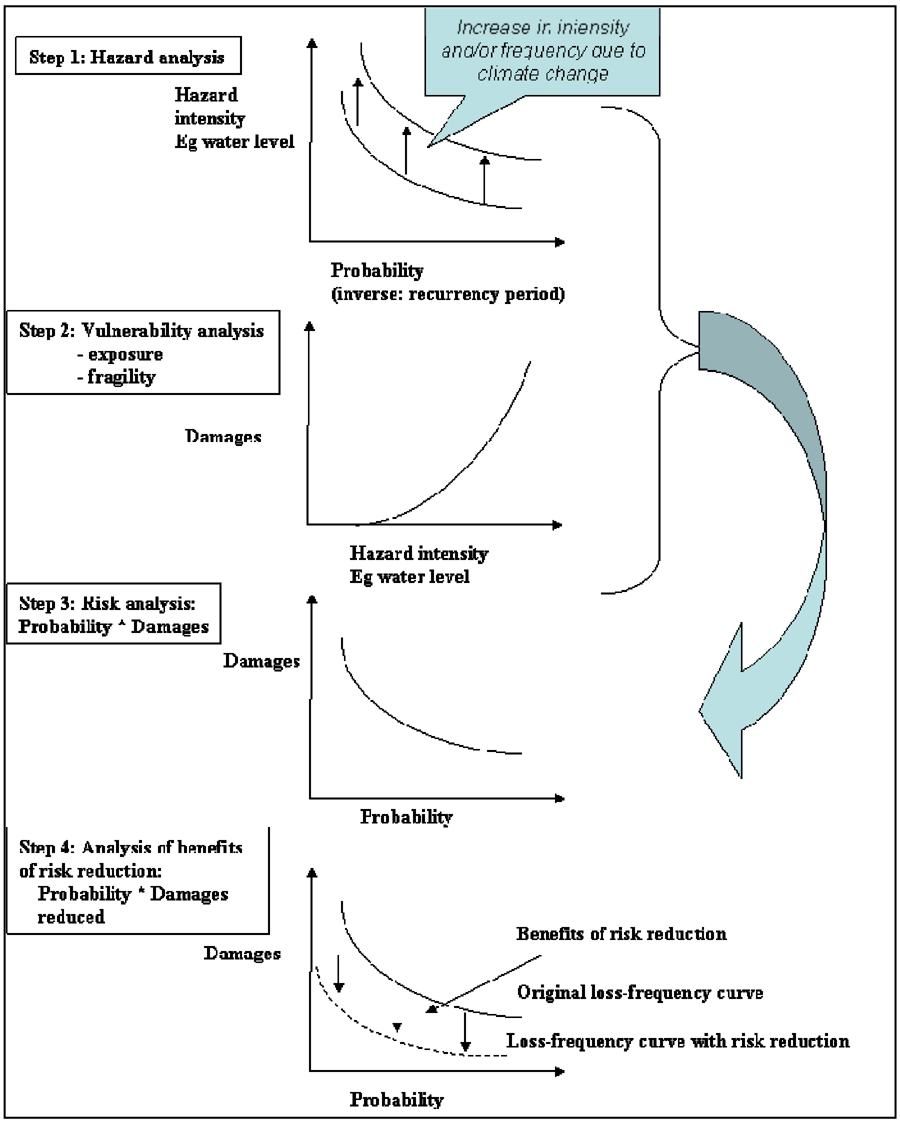

Fig. 10: Quantitative forward-looking framework for estimating disaster risk
Illustration modified based on World Bank, 1996.

2 Options are studied using this framework:

- Flood-proofing of the Bangladesh roads and highways, relevant to the DFID-supported programme "Roads and Highways Policy Management, budgetary and TA Support" (RHD).

- Raising homesteads in Char Areas of Northern Bangladesh within the "Char Livelihoods Programme" (CLP).

4.1 Option 1: Flood-proofing of roads and highways by raising road height to the highest recorded flood and provision of adequate cross-drainage facilities

Bangladesh is covered by a large road and highway network, most of it traversing through the flood plains of the country. The Roads and Highways Department (RHD) is responsible for a huge number of assets in the form of roads, bridges and culverts. Protecting and maintaining about 20,798 kilometers of roads and 14,712 bridges and culverts with an estimated asset value of TK 727,000 Million is of prime importance for the national economy.

Flood loss potentials to roads infrastructure have been huge. In the 1998 and 2004 flood, for example, the direct damage to roads sector is estimated as TK 15,272 and TK 10,031 Million, accounting for 15 and 9 per cent of the total damage respectively. The situation is expected to be deteriorating in the days to come, with the increased extent and intensity of flooding due to potential climate change and sea level rise in future. Hence, it is important to develop flood proofing systems as a response to natural disasters, in designated flood risk zones, to protect life, property and vital infrastructure such as roads. As yet, flood proofing to roads in areas under CLP has not prominently featured in its activities and programmes. As more and more households benefit from raised homesteads (see option 2), the priorities may change and the demand for raised roads is expected to increase.

The maintenance of these assets and protecting them against disasters such as floods is a fundamental requirement for the economy to sustain. It is, therefore, the national policy that all national and regional roads are planned and designed to be constructed for above the highest flood level (HFL). The district roads are planned to be constructed over the normal flood level. It is also the policy that the damages are minimised by measures through increasing openings of bridges and culverts as, it has been observed that inadequate openings of bridges and culverts cause damage to both structures and approach roads.

Historical records show that the roads, which were raised above the 1988/1998 flood-level, suffered minimum damage in the 2004 floods. After the 1988 flood, for example, national highways such as the Dhaka-Chittagong, Dhaka-Mawa-Khulna, Dhaka-Sylhet and Dhaka-Aricha highways were raised by 1 to 1.5 meters above HFL. As a result, these highways suffered no significant damages during the 2004 flood (Rahman 2006).

In recent time, relevant experts suggested that roads constructed along the east-west direction were given extra attention to ensure proper drainage of water, by providing extra spans for adequate passage at the peak flow stage. Experts also warned that the existing bituminous pavements are more susceptible to water than cement-concrete ones. Provision of asphalt concrete topping and hard shoulder can reduce the damage to roads caused by the flow of water over the road surface. Asphalt concrete produce more durable pavements than the usual road with mixed carpeting.

Knowledgeable people also opine that in order to minimize the erosion of the road embankments and vulnerable road sections, slopes have to be protected with hard layers (C.C. blocks with geo-textile); less vulnerable sections should be protected with flood resistant natural turfs and plants like vetiver (Kashful).

Currently there are three types of maintenance:

(1) Routine maintenance, carried out year round (at an approximate cost in the range of TK50,000-70,000 per Km)

(2) Periodic maintenance, carried out in 4 -5 years (at an approximate cost in the range of TK500,000-1500,000 per Km)

(3) Partial/Full/Rehabilitation/Reconstruction (at an approximate cost in the range of TK5000,000 per Km)

The requirement for maintenance depends on the roughness, caused due to inundation and heavy rains, and associated traffic loads. Ironically, routine and periodic maintenance are often overlooked by policy makers, in consequence of which more and more roads are becoming subject to complete rehabilitation over years, turning this to a great backlog. Only recently, a sum of TK10000 Million has been allocated to rehabilitate only a few roads. Had there been regular and routine maintenance no such backlog could crop up at a very short interval of time.

Over and above, pavement designs constructed in the past were generally inadequate to adaptation to floods in terms of alignment, height, widths, slopes and provision of adequate drainage openings. Apart from the roads having been previously constructed at a level lower than HFL, this is one of the reasons why older roads have generally become yet more vulnerable to flood water. For example, relatively older roads, the Commilla–Brahamanbaria highway appears to have now become vulnerable to floods. As a result, it is now planned to undergo full rehabilitation for at least 37 out of 74 Km length. Similar is the case with the Bhariab–Mymensingh road. The development partners while funding these projects have asked to pay proper attention to flood risks. It has been suggested that while undergoing complete rehabilitation such types of roads are raised up to a safe flood level.

Hence, policies, guidelines and technologies are already there but, ironically, these are not properly practiced in real situations, with the exception of, perhaps, new national highways. Hence, it is important that they are enforced at least phase-wise and on a priority basis. The Roads Master Plan (Government of Bangladesh, 2007) also recently reiterated the maintenance of 1 to 1.2 meter freeboard above a 50 year flood, although directives in this respect have been in existence since the time of the floods back in 1987 and 1988. Notwithstanding the above facts, so far, the efforts and resources of the RHD are meagre compared to the enormous dimension of the problem. The proposed option in its entire scope will provide appropriate flood proofing to nearly 800 Km of roads through roads raising across the country.

In the calculations it is assumed that costs and benefits are evenly spread over time, i.e. every year a constant amount is spent for flood-proofing, resulting in a gradual building-up of flood protection. Benefits considered are the avoided infrastructural asset losses (direct losses).

Regional focus and time horizon

This is an option with a national coverage. The National Water Management Plan- NWMP (2001) divided the entire country into eight ecological regions: South Western (SW), South Central (SC), North Western (NW), North Central (NC), North Eastern (NE), South Eastern (SE), Rivers and Estuaries (RE) and Eastern Hills (EH). This option relates to the six major regions of Bangladesh, but does not include the RH and EH region of the country.

The option comprises a long-term programme (25 years) but since the costs would be very high if incurred at one time it is intended that roads raising will be carried out when a particular road is due for full rehabilitation, with priority given to high risk areas. Since the work involves simply the raising of existing roads, environmental impacts would be minimal.

Table 5 shows the estimated regional distribution of roads according to high and low flood risk levels, (NWMP 2001). The distribution refers to year 2000 and it is assumed that, since then, according to government policy all new roads have been constructed keeping in view of the highest flood level of the 1998 flood. It is intended that all national and regional roads not above flood level at present, and one-fifth of the district (feeder) roads in high risk areas only, will be raised by the end of 25 year period.

Table 5: Estimated regional distribution of roads to be raised

Road Type	Risk level	Length of road to be raised, by type and region (Km)						
		SW	SC	NW	NC	NE	SE	Total
National Highways	High	6.7	15.8	19.4	39.6	0.4	7.3	89.2
National Highways	Low	10.3	0.6	12.8	12.5	1.4	9.6	47.2
Regional Roads	High	19.9	7.4	16.1	18.6	2.9	14.6	79.5
Regional Roads	Low	7.7	4.0	41.1	8.9	5.4	9.9	77.0
District Road Type A	High	17.8	34.8	48.3	94.5	4.2	41.2	240.7
District Road Type A	Low	31.9	38.8	62.8	108.8	8.4	26.7	277.5

Source: Government of Bangladesh, 2001.

The investment period for the option upon which the cost benefit analysis is undertaken is 25 years, reflecting existing practices in RHD.

Cost estimates

The option is targeted at the flood proofing needs of key portions of Bangladesh's highway network. Specifically, some 170 Km of national and regional roads and some 518 Km of district (feeder) roads in high risk areas will be raised by 1 meter. Under the option, about 124 km of national and regional roads in low risk area will be raised by 0.5m.

Table 6 presents cost estimates for road raising and related drainage improvements by roads category of high and low risk areas. In total, about TK 8,794 Million will be required for the implementation of the option. The costs estimates have considered an average two culverts per Km (for cross-drainage facilities) for each category of roads, instead of currently practiced 0.71 culvert per Km. An average culvert costs 1 million Taka. The road maintenance cost assumed to be at the rate 4% will have to be incorporated while estimating NPV.

Table 6: Costs estimates by category of roads by risk level

Roads type	Length of roads to be raised (Km)	% of total in each category	Rate Tk/Km (2007 prices)*	Total (TK-Million)
In high flood risk areas				
National Highway	89.2	2.5	13.8	1,228
Regional Highway	79.5	1.9	13.2	1,053
District (Feeder) Roads- Type A	240.7	3.7	9.9	2,388
District(Feeder) Roads – Type B	277.5	4.2	8.8	2,455
Subtotal	686.9	3.3		7,125
In low flood risk areas				
National Highway	47.2	1.3	13.8	650
Regional Highway	77.0	1.9	13.2	1,020
Sub-total	124.2	0.6		1,670
Grand Total				**8,794**

Assessing risks and benefits of DRM

Benefits of the option would be the avoided rehabilitation costs due to floods. Table 7 lists the major riverine floods that have occurred in all of Bangladesh, its impacts on the roads sector and estimated recurrency.

Table 7: Potential costs of flood to roads sector : Bangladesh (2007 prices)

Floods	Cost of flood (Million TK- 2005-06 price)				Return period	Exceedance probability
	National	Regional	District	Total		
1987	307	852	4240	5399	13.0	0.077
1988	369	1021	5089	6479	55.0	0.018
1998	875	2404	11995	15273	90.0	0.011
2004	572	1577	7882	10031	12.0	0.083
Average, expected cost of floods	531	1463	7301	9295		

Source: compiled form Siddiqui, K. U. and Hossain, A. N. H. A. (2006), Islam (2005).

Note: Actual cost of rehabilitation per km (for 2004 flood) is used to estimate potential cost of floods in various events; US$ = 70 Taka (approx).

In order to smoothen loss probability curve, $Y = Ae^{BX}$ ($\text{Log } Y = \text{Log } A + BX$) is fitted using data on potential cost of floods of actual flood events where Y is the cost of flooding in selected events, and X represents the return period. The estimated equation is Y = 8.724 + 0.008 (Return Period), (Table 8). This is then combined with exceedance probabilities to arrive at annual benefits, which is equivalent to expected annual flood losses to the roads sector.

Table 8: Flood risk for the road sector

Floods (Return period)	Cost of flood (Million TK- 2007 prices)						
	National	Regional	District	Total	Baseline	b1 2020	b1 2050
10 Yr	363	1,007	5,012	6,382	10.0%	14.3%	25.0%
20 Yr	401	1,113	5,540	7,054	5.0%	6.7%	13.3%
30 Yr	444	1,230	6,123	7,796	3.3%	4.3%	9.1%
50 Yr	542	1,502	7,478	9,521	2.0%	3.3%	6.7%
75 Yr	696	1,928	9,602	12,226	1.3%	3.6%	4.5%
90 Yr	808	2,241	11,162	14,211	1.1%	3.1%	4.0%
E(X)	**100**	**277**	**1,377**		**1,754**	**2,919**	**5,004**

Based on the assessment of the projected change in frequency of impacts of severe flooding presented in the climate science inputs to the ORCHID screening process, the above curve can be transformed to account for increased frequency in the b1 2020 and b1 2050 scenarios (fig. 10).

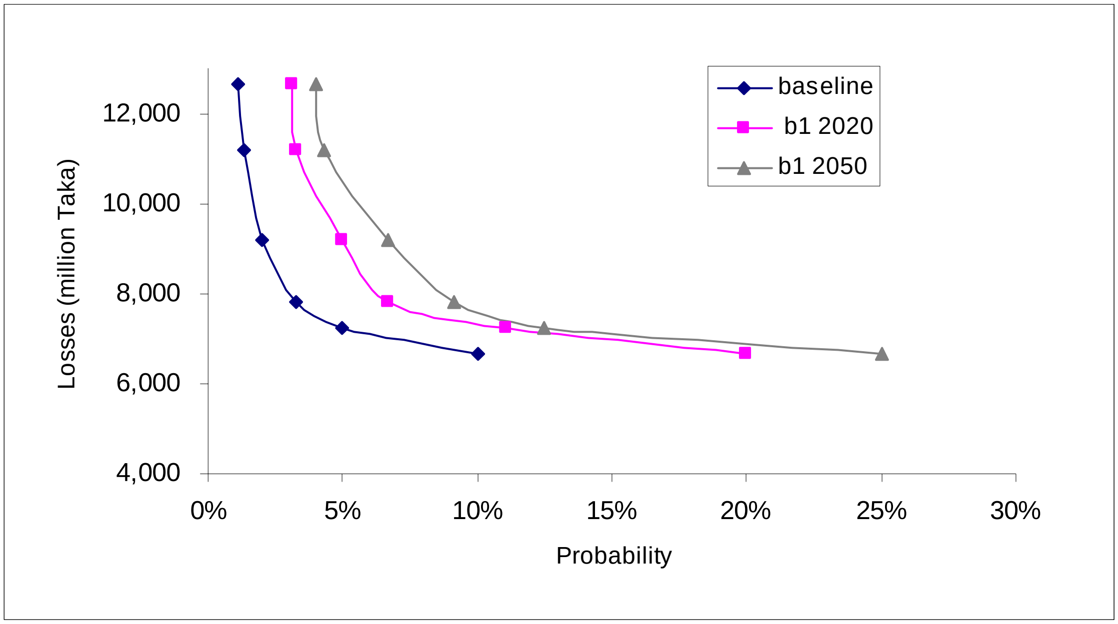

Fig. 11: Potential impacts of flooding on the road sector now and in the future (2020, 2050)

The expected value of the benefits is considered to equal the area under the curve, assuming that roads and highways are flood-proofed to the highest ever-recorded flood and floods can thus be avoided.[5] The annual increase in risk from adding in these climate change scenarios to the hazard burden is estimated to amount to 2.6% per year, where the assumption is taken that increases over time are linearly distributed.

Results

Based on the estimates of costs and benefits, the economic efficiency of this option can be estimated. The following table outlines the process of estimating the BC ratio, NPV and IRR. For each given year over the time horizon of 25 years, costs and benefits and net benefits are displayed both in discounted and non-discounted format in constant 2007 values for a (high) discount rate of 12%, the rate most commonly assumed in similar exercises.[6] Dividing benefits by costs leads to the B-C ratio, subtracting costs from benefits to the net present value (NPV), and the IRR is calculated as the rate that discounts the NPV to zero.

[5] In reality, full protection against extreme events is normally not possible and cost-effcient.

[6] The return on capital in most developing countries is considered to be between 8-15% in real terms and often 12% is used as a default value (see, for example, OAS 1991; ADB 2001).

Table 9: Overview over CBA calculations for RHD option for best estimate and 12% discount rate

Discount rate	12%							
Year	Calendar Year	Costs	Benefits	Net benefits: benefits-costs	Discounted costs	Discounted benefits	Discounted net benefits	
1	2007	352	70	-282	352	70	-282	
2	2008	352	144	-208	314	128	-186	
3	2009	352	217	-134	280	173	-107	
4	2010	352	291	-61	250	207	-43	
5	2011	352	365	13	224	232	8	
6	2012	352	438	87	200	249	49	
7	2013	352	512	160	178	259	81	
8	2014	352	586	234	159	265	106	
9	2015	352	659	308	142	266	124	
10	2016	352	733	381	127	264	138	
11	2017	352	807	455	113	260	147	
12	2018	352	880	529	101	253	152	
13	2019	352	954	602	90	245	155	
14	2020	352	1028	676	81	236	155	
15	2021	352	1101	750	72	225	153	
16	2022	352	1175	823	64	215	150	
17	2023	352	1249	897	57	204	146	
18	2024	352	1322	971	51	193	141	
19	2025	352	1396	1044	46	182	136	
20	2026	352	1470	1118	41	171	130	
21	2027	352	1543	1192	36	160	124	
22	2028	352	1617	1265	33	150	117	
23	2029	352	1691	1339	29	140	111	
24	2030	352	1764	1413	26	130	104	
25	2031	352	1838	1486	23	121	98	
	Sum	**8794**	**23853**	**15058**	**3090**	**4998**	**1907**	NPV
							1.62	B/C ratio
							12.1%	Estimated internal rate of return

According to table 9, for a discount rate of 12%, the net present value would be TK 1,907, the B-C ratio 1.6 and the estimated internal rate of return of about 12% (thus the same as the discount rate). For all these criteria, the suggestion of this analysis would thus be to conduct the project (for the internal rate of return it would just be fulfilled).

Table 10 and figure 11 show the effects of varying the discount rates and costs/benefits by+/- 50% in order to account for uncertainty. Although very costly and an option with national coverage, the flood-proofing of RHD investments seems to be efficient given the assumptions taken. For the best estimate case, a range of 1.2-2.7 is calculated; thus for this set of assumptions, the option would be beneficial. It would mostly still be larger than 1 with more pessimistic assumptions such as costs increasing by 50%. If however, under very pessimistic assumptions, costs are increased and benefits are supposed to be decreased by 50%, then for all discount rates considered the option would not be efficient anymore.

Table 10: Results in terms of B-C ratio for current and future conditions

Scenario\Discount rate	**0%**	**5%**	**10%**	**12%**	**15%**	**20%**
Best estimate	2.7	2.2	1.8	1.6	1.4	1.2
Costs +50%	1.8	1.5	1.2	1.1	1.0	0.8*
Costs +50%, benefits -50%	0.9*	0.7*	0.6*	0.5*	0.5*	0.4*

*Not efficient

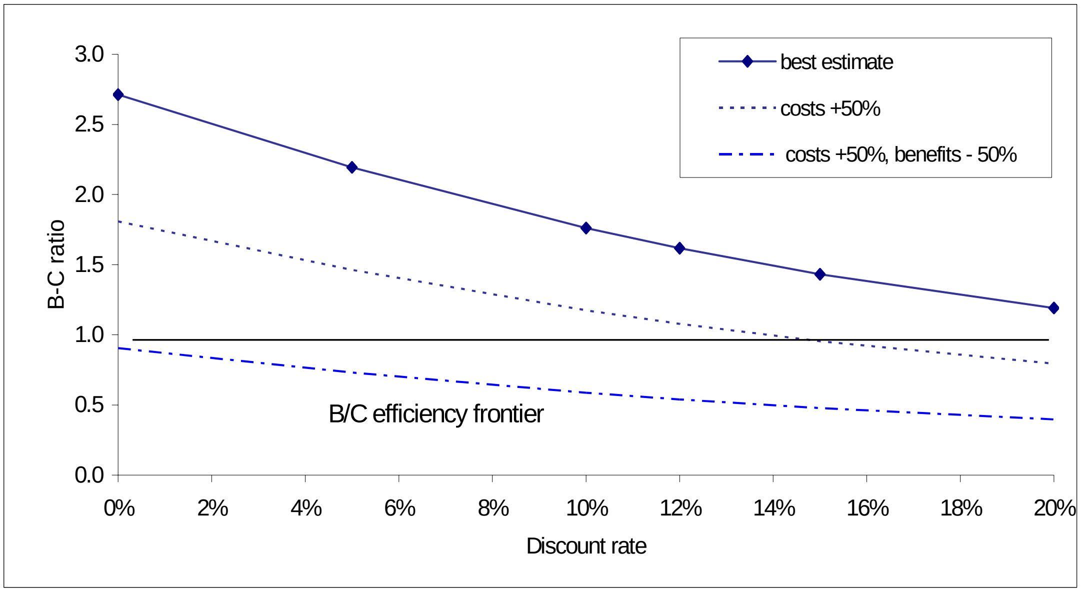

Fig. 12: BC ratios for RHD option for best estimate and sensitivity analysis

Concluding remarks

Obviously, the raising of roads as suggested is highly expensive. However, as this is a long term project with national coverage the roads raising should be considered when a particular road is due for major rehabilitation. This way, substantial costs can be reduced, as long as costs and benefit fall broadly within the range of estimates. Also, apart from protecting roads infrastructure, the roads raising option will also create a number of direct and indirect benefits, which are not factored into the analysis, but would increase benefits and should be kept in mind:

- Social benefits which are largely intangible and difficult to quantify:
    - Avoidance of loss of human lives and livestock,
    - Use as a refuge during the emergency period,
    - Reducing stress and sufferings of flood victims,
    - Facilitation of the movement of relief goods during flood emergencies.
- Avoidance of inventory damage:

Substantial inventory damage can be avoided. Besides, protecting foodgrains and livestock fodder can also be a major benefit during floods. It is estimated that over 81,000 households will be able to take refuge on the raised roads during extreme floods. Additionally, there will be substantial damage that can be avoided (to e.g., inventory and livestock) by using the raised roads and highways. This is estimated to save in the tune of TK 581 Million in the event of a 50 year flood, for example (at the rate of TK 7,165 per household).

- Transport benefits

Traffic disruption is by far the most common type of disruption caused by floods. Indirect costs due to traffic disruption arise in the form of additional transport costs (comprising fuel etc) and opportunity costs by delay in journey. In developed countries, such costs of disruption can be substantial. In Bangladesh, however, dependencies on roads during floods are likely to be largely offset by 'natural' redundancies created by wide-spread waterways through a large number of water transports. Even then, there will be considerable indirect costs, arising out of time consuming commuting by water transports.

- Poverty reduction through employment generation:

The option, when implemented, will generate employment opportunities largely for the disadvantaged groups of people, particularly women, especially during construction. Additionally, during repair and maintenance phase there will be some extra employment. Total person-days that will be generated by earthwork alone estimates are 4 million. Total wages that will be earned by way of this employment estimates as TK 600 Million. Obviously, this will have some implication to poverty reduction.

4.2 Option 2: Flood proofing of individual homesteads in the Char areas against 20 year floods by means of constructing raised earth platforms.

The second option considered in this analysis involves flood proofing individual homesteads against a maximum of 20 year floods on riverine islands, known as Chars, in Bangladesh. The option is already under implementation as part of the Chars Livelihoods Programme and involves constructing earth platforms on beneficiaries land for the unit of a bari (homestead with 4 households).

The riverine areas of Bangladesh are home to the poorest and most vulnerable communities in the country with over 80 per cent living in extreme poverty. Inhabitants of these areas live under serious risk of frequent flooding. The Bangladesh National Water Management Plan emphasizes coping with inland floods rather than managing them. In the past, greater reliance has been placed on embankments and drainage schemes, which are primarily designed for agriculture protection. The protection of non-agricultural sectors such as human habitation and infrastructure has received far less attention in the past, despite the significant flood loss potentials of such sector. In the 1998 and 2004 floods, for example, the direct damage to residential sectors accounted for 20 to 33 per cent of the total damage, and 40 to 44 per cent of the total non-agricultural damage (Islam, 2006).

With this background, the Homestead Raising Option in Char Areas is concerned with providing proven technologies in the form of raised households to some 2.5 Million people in the main river Char lands. Flood proofing through raising of houses, roads, water supply/sanitation facilities and other infrastructure above flood level reflects traditional practice in Bangladesh. Not all households have the resources to do this, however, especially in the unprotected Char areas near the major river channels.

The option is to construct earth platforms on beneficiaries land, establishing an unit for a ‘bari’ (homestead), which comprises 4 houses with a total of 20 people on 600 m2 area, each house being on a 150 m2 area, to protect against a the height of a flood with a recurrence interval of 20 years. The adaptation option presented here considers the flood proofing of an area to accommodate four dwellings, a hand tube well and a toilet. It is assumed that the inhabitants will dismantle their individual houses and reconstruct their individual houses on a common platform. As erodible soils can be washed away by wave action during floods, protection and/or regular maintenance may be required.

Fig. 13: Women involved in homestead raising in the Chars, Courtesy CLP

Linkages with Char Livelihood Programme (CLP) activities and rationale for cost benefit analysis of the option

The lives of the Char people are closely related to the dynamics of the river flows and the resultant formation and erosion of Chars. Thus, Char communities are extremely vulnerable to erosion and flooding. With this background, the CLP aims to improve the livelihood of the poor in the Char areas by reducing vulnerability of dwellers, through targeted provision of, among others, infrastructures thereby improving the resilience of the community to environmental shocks. However, these people have the least resources to afford to build such infrastructures.

The current study considers security of houses as closely linked with the reduction in overall vulnerability of Char people. Hence, it is of prime importance to provide secure houses to Char people. In fact, CLP has already targeted towards achieving this through raising of homesteads. In the mean time, it has already raised homesteads to more than 24,000 Char people, with a target of another 32,000 by the end of this fiscal year.

The CLP has recently targeted plantation including through Vetiver grass, Durba grass and trees to protect slopes from erosion due to flooding. It has recently prioritised which homesteads should be selected for earthworks to raise their plinth level. In this respect, it has also adopted a consistent approach towards the promotion of improved latrine technologies.

Small-scale water supply systems are not recommended for the Chars. Motorized pumping equipment, which incur greater operational costs, associated with the cost of fuel and a water distribution system, often fail during the most critical time of floods. The CLP thus recommends for low-cost, improved water supply activities.

Notwithstanding the above facts, so far, the efforts and resources of the CLP are small compared to the enormous dimension of venture for the vast number of people. Moreover, homestead raising on a cluster basis has not yet featured in CLP activities and programmes.

Regional focus and time horizon

The Char areas in this option refer to the project area delineated by Char Livelihoods Programme. The option will focus on one of the main Char areas comprising five districts – along the Brhmaputra river, stretching from Kurigram in the north to Sirajganj districts in the south. The other three districts are Jamlpur, Gaibanda and Bogra. About 1000 villages in 20 Upazilas in the Brahmaputra Char lands will be covered under the option. Although the option refers to Char areas this could also be adopted in any areas vulnerable to flooding, including coastal areas. A 25 year project time horizon is assumed.

Cost estimates

Knowledge of the maximum flood level in Char areas is critical for the design height of the raised homestead. It is difficult to assess exactly to what extent individual homesteads have to be raised as land level in an area varies considerably from house to house, and location to location. It is also difficult to assess what return period this equates to. In fact, there is no real scientific basis for quick assessment unless there is any detailed-level land use, land level and hydrological survey relating to the area. This is more critical for such a short assignment. However, the maximum flood level has been based upon the living memory of local people as adopted by CLP.

Based on discussion with local people and CLP personnel, an average three feet raising (0.91 meter) is suggested for a flood such as 2004 event with an approximate return period of 15 years locally. An additional 0.61 meter (2 feet), however, has to be added to this level as a freeboard. This allows to assume that a height of 1.52 meter (from ground level) will protect from approximately maximum of a 20-yr flood. In other words, this is expected to protect against a flood level of 1.22 meter (from house floor level), assuming an average floor height of .30 meter (one foot). It is gathered that almost 100 percent of the Char inhabitants are said to be at flood risk even to a 2 year event although some 33 per cent are reported to be most vulnerable. Average floor heights of houses as elsewhere in the country are assumed in this analysis.

The option is involved in providing an earth platform to permit construction of dwellings and the associated facilities on raised ground to protect against a minimum flood level. In other words, these would be constructed such that flooding does not affect their day-to-day functioning. The option presented here considers the flood proofing of an area to accommodate four dwellings, a hand tube well and a latrine. The level to which the land is raised takes into account not only the maximum observed flood level (probably up to a 20-year flood), but the effects of sea level rise due to climate change to some extent.

The HS Option can be divided into two sub-options depending on whether or not the community will bear any costs associated with this. Under the HS Option (A), the CLP project will raise one common platform for 4 dwellings, each with 150 M^2 area and will reconstruct individual houses. Other infrastructure provision such as tube wells and sanitation will also be constructed by the project. Under the HS Option (B), the project will only raise the common platform while the beneficiaries will reconstruct their individual houses, including making other infrastructure provision such as tube wells and sanitation. The analysis is carried out for both the cases.

Cost estimation has been carried out for the above typical system and its details are given in Table 11. The first sub-option assumes that the cost of water supply, toilets and reconstruction of buildings will be borne by the Project. According to the estimate, the capital investment cost per household benefited amounts to about TK 16,000 for the first sub-option. For the second sub-option, the capital investment cost per household benefited amounts to about TK 10,000.

Raising land for buildings above flood levels is assumed to eliminate the damage caused by flooding up to that respective flood level. Raising of other facilities and infrastructure can also reduce or eliminate the disruption caused by the floods.

Table 11: Information and costs for option homestead raising option

Item	Estimates	Major assumptions
Population in Char areas under CLP	2.5 Million	
Average household size	5	
No. of 'bari' platforms (consisting of 4 dwellings) to be raised	125,000	
Average size of each platform (4 dwellings @ 150 M^2)	600	

No. of dwellings served	500,000	
No. of people served	2,500,000	
Working life	25 Years	
Average quantity of earthwork (for each 'bari' platform consisting of 4 dwellers) (600 m^2 x 1.22 m)	732 m^3	Construction on beneficiaries land
Cost of earthwork per m^3 (2007 price)	TK 54	
OPTION A Cost for each bari platform (2007 price) Cost of earthwork Cost of compaction, turfing & plantation[7] Cost of dismantling/reconstruction Cost of CLP-type (raised) tube well (1 for 4 dwellers)[8] Cost of CLP-type tube-well platform (1 for 4 dwellers) Cost of CLP-type latrine (4 for 4 dwellers @TK 3,300)[9] Total cost for each bari (4 dwellers) Total cost for each households	 TK 39,528 TK 645 TK 4,300 TK 4,837 TK 1,828 TK 14,190 TK 65,328 **TK 16,332**	Cost of water supply, toilets and reconstruction of buildings will be borne by the Project
OPTION B Cost for each bari platform (2007 price) Cost of compaction, turfing & plantation Total cost for each bari (4 dwellers) Total cost for each household	 TK 39,528 TK 645 TK 40,173 **TK 10,043**	Cost of water supply, toilets and reconstruction will be borne by the beneficiaries.
Total cost of the option in Char areas OPTION A OPTION B	TK 8,166 Million = $117 Million TK5022Million = $ 72 Million	$=Tk70
Operation and maintenance cost	2%	To be borne by the Project

Table 12:
Table 13: Additionally, 2 percent of total cost will be required for operation and maintenance costs, which is to be borne by the Project
Table 14:

Assessing risks and benefits of DRM

Identifying appropriate benefits of this option is more difficult than its costs as there is much more uncertainty in this respect. Depths, duration and frequency of flooding, and land levels and floor heights of individual houses are among the uncertainties. Direct (structural and inventory) in terms of reconstruction costs and indirect (income) losses are included in the analysis based on Islam (2005, 2006). Baseline probabilities are based on Islam (2005, 2006), for the future Hassan and Conway's estimates from the climate science inputs to the ORCHID screening process are employed. Benefits will be equal for both the two sub-options, HS(A) and HS(B).

Following a detailed information collection is beyond the scope of the current study and one has to adopt some broad assumptions based on general discussion with the Char managers and Char dwellers. The method of Triangulation is adopted to crosscheck information from various sources. The major sources of information used in this analysis are CLP secretariat, Government of Bangladesh

[7] The standard of compaction, turfing & plantation to protect from erosion in 1:2 ratio is adopted from CLP
[8] The tube well refers to a raised one (to ensure supply of drinking water during floods) according to CLP-introduced standard.
[9] Latrine includes 5 concrete rings and a super structure according to CLP-introduced standard.

(2001), Islam (2005, 2006) and the potential beneficiaries themselves. Perceptions of local Char people were useful in collecting information on floods, its frequency, depths and durations.

In relation to flood events and from the perspective of the residents, the following factors are of specific importance and these have implications on the engineering design of flood protection structures and flood response strategies:[10]

a) Frequency of flooding

b) Depth of flooding

c) Duration of flooding

d) Land levels and height of platform

e) Susceptibility of building materials to water

Two types of houses are considered for Char areas (1) EC- Earthen floor, CI sheet wall; and (2) ET- Earthen floor, Thatched wall. Field survey and discussion with CLP personnel suggests the existing proportions of these two house types to be 33 and 67 per cent respectively. The design and cost of raised tube wells and latrines are adopted from CLP. The option will have the provision for one raised tube well and four latrines (one each for four dwellers) on the platform.

Depths and duration of flooding are assumed as follows (based on quick survey in Char areas and Islam (2005, 2006):

Table 15: Important assumptions taken

Return period	Average depth (above floor level) (Meter)	Duration of flooding (days)
2 Yr	Floors not inundated, only courtyard flooded	7
5 Yr	0.30	7
10 Yr	0.61	14
20 Yr	1.22	14

Appropriate deflators of building materials (for structural damage) and national income (for inventory damage) are used in the benefit assessments, to convert to 2007 prices.

Adverse impacts of floods on health are considerable as, for example, there is close correlation between flooding extent and incidence of water borne diseases such as diarrhoea and dysentery (r=0.66 with more than 99 per cent significance level). The benefits relating to welfare cannot be quantified. The proposed option has introduced some low-cost and improved water supply and sanitary activities by which protection from water borne diseases will be ensured. Such types of benefits, however, have not been incorporated in the analysis. As regards working life, Government of Bangladesh (2001) suggested for a 25 year life for a project such as this.

[10] Knowledge of the maximum flood level in Char areas is critical for the design height of the raised homestead. It is difficult to assess exactly to what extent individual homesteads have to be raised as land level in an area varies considerably from house to house, and location to location. It is also difficult to assess what return period this equates to. In fact, there is no real scientific basis for quick assessment unless there is any detailed-level land use, land level and hydrological survey relating to the area. This is more critical for such a short assignment. However, the maximum flood level has been based upon the living memory of local people as adopted by CLP, which includes a freeboard of 0.6 meter to take into account of, among others, probably climate change impacts on flooding.

Table 16: Flood Risk now and in 2020 and 2050

Structural damage (main house) avoided (2007-TK)	Inventory damage avoided (2007-TK)	Income loss (2007-TK)	Other damages avoided*	Sum	Prob. baseline	Prob. b1 2020	Prob. b1 2050
591	0	355	0	946	50%	67%	67%
2,366	2,103	710	478	5,657	20%	33%	43%
5,159	5,594	1,419	1,911	14,084	10%	20%	25%
7,468	9,052	1,774	3,822	22,115	5%	11%	13%
				Expected losses (TK)	**4,118**	**7,790**	**9,528**

*Other damages include clean-up cost, loss of livestock, trees, gardens and other houses (including livestock shed, kitchen, toilets etc)/

Avoiding impacts up to the 20 year flood (5% recurrency) leads to benefits. These benefits in terms of expected values are tabulated for the baseline, 2020 and 2050 cases in Table 13. As the option has a lifetime of 25 years, a climate-change induced annual increase of 2.6% in losses and benefits based on above calculations was used up to the year 2031 as for the RHD option.

Results

Calculating CB-ratios as before for current and future climatic conditions, would lead to the following results in terms of BC ratio (table 14 and 15 and fig. 13).

Table 17: B/C ratio for homestead option for Option A

Interest rate	0%	5%	10%	12%	15%	20%
Baseline estimate	2.8	2.1	1.6	1.4	1.3	1.0
Costs +50%	2.4	1.7	1.2	1.1	0.9*	0.7*
Costs +50%, benefits – 50%	1.2	0.9*	0.6*	0.6*	0.5*	0.4*

*Not efficient

Table 18: B/C ratio for homestead option for Option B

Interest rate	0%	5%	10%	12%	15%	20%
Baseline estimate	3.2	2.6	2.1	1.9	1.7	1.4
Costs +50%	2.9	2.2	1.7	1.5	1.3	1.1
Costs +50%, benefits – 50%	1.4	1.1	0.8*	0.8*	0.7*	0.5*

*Not efficient

Similar results as for the RHD option are obtained with slightly higher B-C rations:

- For best estimate cases, suboptions A and B seem to be beneficial given the assumptions; option B scores higher, as costs for the project are reduced by residents helping out.
- If more pessimistic assumptions on costs and benefits are taken, the suboptions eventually become inefficient with rising discount rates.

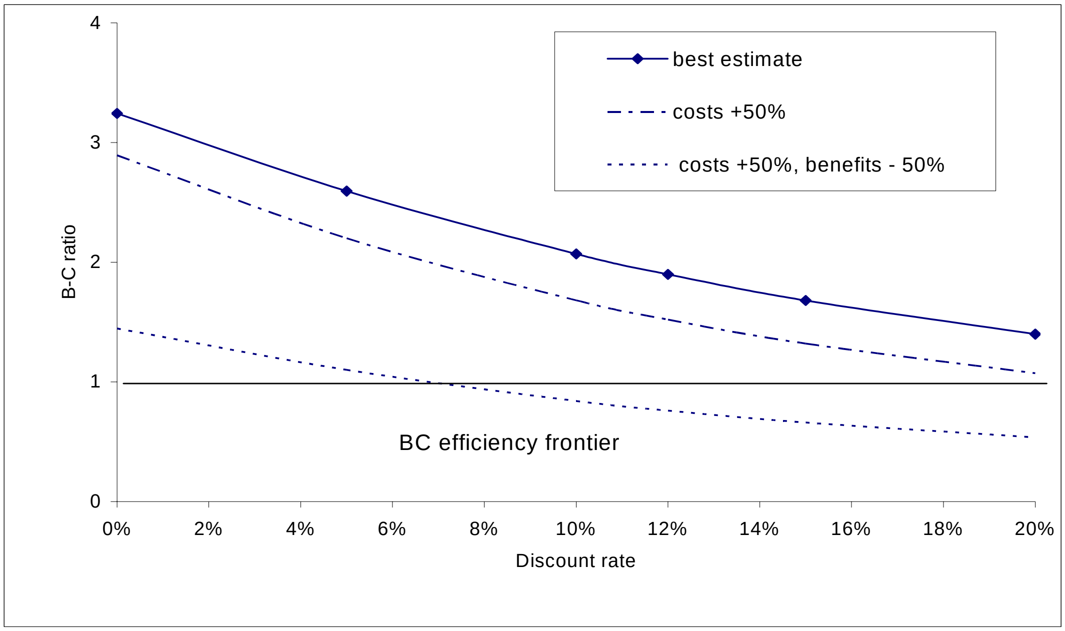

Fig. 14: B/C ratio for homestead option B as function of discount rate

Apart from flood protection created and thereby huge flood damages avoided by the option, local people in disaster-prone and poverty-stricken Char areas will gain opportunities to earn additional income should this option be implemented. In particular, it will provide considerable opportunity for women employment in earthwork. This was also apparent during a field visit during this project to the Char areas that villagers by and large expressed keen interest in undertaking a venture involving such a huge earthwork. Besides, raising of homesteads on a cluster basis leads to some potential social gains, in terms of creation of community cohesion, the benefits which are intangible but may be significant to the society.

The CLP beneficiary households are by definition extremely poor. Expecting them to finance the Project, even partly, would mean further deterioration of their economic condition. In this respect, the Option HS (A) (one without participation from the community) may be more suitable for the Char people. However, the beneficiaries may feel encouraged in contributing in earthwork.

SECTION 4: CONCLUSIONS

Methodology

This chapter discussed the appraisal of economic efficiency of selected adaptation options to extreme climate-related event risks of the DFID development assistance portfolio in Bangladesh via Cost-Benefit Analysis (CBA). The methodology developed was tested as a pilot study for selected intervention options within the DFID Bangladesh portfolio as part of the ORCHID project. Such an approach may inform the prioritization and implementation of cost-effective disaster risk management and climate adaptation ("no-regret") options that help with coping with current and future extreme events as possibly increased in intensity and/or frequency by climate change.

Economic risk and the economic efficiency of selected adaptation options of the DFID development assistance portfolio in Bangladesh is estimated by means of Cost-Benefit Analysis (CBA) accounting for uncertainty and dynamic driving forces of hazards, vulnerability and exposure. A key concept employed in this analysis is the probabilistic representation of risk and benefits of risk reduction by loss-frequency functions. For valuing benefits of public sector interventions, the expressed preference-approach was used using available market prices for goods, such as used for reconstructing a damaged building. This involves adding up potential avoided impacts in terms of reconstruction costs. The revealed preference approach is more common and followed for disaster risk management due to the general availability of some data, while for the alternative revealed preference method, specific surveys would be required.

Two frameworks for the estimation and monetary quantification of disaster risk for the purposes of a CBA were presented:

- The more rigorous *risk-based* framework (forward-looking, risk-based) combining data on hazard and vulnerability (fragility and exposure) to an estimate of risk and risk reduced; and
- The more pragmatic *impact-based* framework relying on past damages (backward-looking, impact-based), focusing on past damages and modifying those to come to a first-order understanding of risk.

The appropriate approach to be used depends on the objectives of the specific CBA conducted, the data situation and available resources and expertise.

Estimating extreme event risk and the benefits of risk reduction is fraught with substantial uncertainty, particularly so in this case, as disasters by definition are low-frequency, high consequence events. Uncertainties are among others associated with estimates of hazard and changes thereof, for example due to climate change, exposure of assets and people, fragility (the degree of damage for a given level of hazard intensity, the benefits of risk reduction, the proper choice of the discount rate and different cost concepts used for valuing impacts. In this assessment, due to data limitations and the scope of the study, it was not possible to conduct a quantitative uncertainty analysis (for example using confidence intervals); rather, sensitivity analysis was used to vary costs and benefits of options as well as the discount rate. The sensitivity of results to assumptions of those parameters and variables (as often in CBAs) was found to be considerable.

Results

In order to set the stage for the CBA analysis and specific adaptation options, aggregate risk of flooding for economic asset risk for all of Bangladesh for now, in 2020 and 2050 under possible climate change is conducted. Economic assets losses today are estimated to amount to 0.6% when measured as a ratio of GDP with a 50 year event (an event with an annual recurrency probability of 2%) possibly consuming about 5.8% of GDP. In the future, based on estimations of increasing frequency of flooding in Bangladesh due to climate change these losses may increase or decrease depending on the amount of adaptation assumed. If no adaptation is assumed (as is standardly done in similar assessments), annual average losses could increase to 0.7% and 0.75% of GDP in 2020 and 2050 (50 year events: 7.0 and 7.3% GDP). If significant adaptation as in the past, where for example, loss of life per event was reduced by two orders of magnitude over a 30 year period, is assumed, annual losses would decrease to 0.5 and 0.2% of GDP for 2020 and 2050 (50 year events: 4.6 and 1.9%). Uncertainty around these estimates and the assumptions utilized, while hard to quantify, is considerable and should be kept in mind. Accordingly, numbers should be understood in terms of orders of magnitude.

These estimates indicate the importance of adaptation (and assumptions on it) have for thinking about climate change and climate change policy. The representation of adaptation in this top-down assessment of necessity is broad-brushed, locale-unspecific and based on adaptation that occurred in the recent past. A key question for this assessment and the adaptation discussion in general (for example see Stern, 2007) is the scope for such adaptation and whether it will occur autonomously or in a planned manner. In order to shed more light on these crucial issues, CBAs for two specific ongoing and planned adaptation options within the DFID-Bangladesh portfolio were analyzed in a more risk-based, bottom-up approach.

The first option considered was the flood-proofing of roads and highways by raising this infrastructure above the highest ever-recorded flood levels within the DIFD-sponsored programme “Roads and Highways Policy Management, budgetary and TA Support” (RHD). Specifically, some 170 Km of national and regional roads and some 518 Km of district (feeder) roads in high risk areas will be raised by 1m. Further, about 124km of national and regional roads in low risk area will be raised by 0.5m. As the option comprises a long-term programme and since the costs would be very high if incurred at one time, it proposes action when a particular road is due for major maintenance or re-surfacing, with priority given to high risk areas. The maintenance of these assets and protecting them against disasters such as floods is a fundamental requirement for the economy to sustain.

Benefits considered were the avoided infrastructural rehabilitation costs due to floods. Although an option with national scope, specific fragility and risk functions are employed for estimating risk and risk reduced. Furthermore, increases in hazard frequency as determined in the climate science inputs to the ORCHID screening process are studied and are taken to increase risk by 2.6% per annum. Although very costly, the flood-proofing of RHD investments seems to be efficient given the assumptions taken. For the best estimate case, a range of 1.2-2.7 is calculated; thus for this set of assumptions, the option would be beneficial. It would mostly still be larger than 1 with more pessimistic assumptions such as costs increasing by 50%. If however, under very pessimistic assumptions, costs are increased and benefits are supposed to be decreased by 50%, then for all discount rates considered the option would not be efficient anymore. This exemplifies the need, given lack of better data, for varying input parameters and studying the sensitivity of results.

Also, apart from protecting roads infrastructure and losses in case of an event, the roads raising option will also create a number of direct and indirect benefits, which are not factored into the analysis, but would increase benefits and should be kept in mind. These are intangible social benefits such as the avoidance of loss of human lives and livestock, use as a refuge during the emergency period and the reduction of stress and sufferings of flood victims, avoided inventory damage, transport benefits as traffic disruption is limited and finally poverty reduction benefits through employment generation.

The second option considered in this analysis involves the flood proofing individual homesteads against a maximum of 20 year floods on riverine islands, known as Chars, in Bangladesh. The option is already under implementation as part of the Chars Livelihoods Programme (CLP) and involves constructing earth platforms on beneficiaries land for the unit of a bari (homestead with 4 households). The lives of the Char people are closely related to the dynamics of the river flows and the resultant formation and erosion of Chars. Thus, Char communities are extremely vulnerable to erosion and flooding. With this background, the CLP aims to improve the livelihood of the poor in the Char areas by reducing vulnerability of dwellers, through targeted provision of, among others, infrastructures thereby improving the resilience of the community to environmental shocks. However, these people have the least resources to afford to build such infrastructures and thus need public and donor support.

The homestead option was divided into two sub-options depending on whether or not the community will bear any costs associated with this. Under the Option A, the CLP project will raise one common platform for 4 dwellings, each with 150 M^2 area and will reconstruct individual houses. Other infrastructure provision such as tube wells and sanitation will also be constructed by the project. Under Option B, the project will only raise the common platform while the beneficiaries will reconstruct their individual houses, including making other infrastructure provision such as tube wells and sanitation. The analysis is carried out for both the cases.

Economic damages considered and benefits as they are avoided were:

- Structural damages to the dwellings house,
- Inventory damage avoided,
- Income loss, and
- Other damages avoided such as clean-up costs.

Similar results as for the RHD option are obtained with slightly higher B-C ratios.

- For the best estimate cases, options A and B seem to be beneficial given the assumptions and a range of BC ratios of 14.-3.2 was calculated; option B scored higher, as the costs for the project are reduced by residents helping out.
- If more pessimistic assumptions on costs and benefits are taken, the suboptions eventually become inefficient with rising discount rates.

Apart from flood protection created and thereby huge flood damages avoided by the option, local people in disaster-prone and poverty-stricken Char areas will gain opportunity to earn additional income should this option be implemented. In particular, it will provide considerable opportunity for women employment in earthwork. This is also apparent during our field visit to Char areas that villagers by and large expressed keen interest in undertaking a venture involving such a huge earthwork. Besides, raising of homesteads on a cluster basis leads to some potential social gains, in terms of creation of community cohesion, the benefits which are intangible but may be significant to the society.

Outlook

Extreme events, their potential impacts and the scope for adaptation are gaining in importance in the policy debate on climate change, also due to increasing empirical evidence and studies on climate change-induced increases in intensity and frequency of extremes such as cyclones and flooding. The representation of extreme event risk and adaptation within modelling approaches is emerging, but there is considerable scope for making better use of improved modelling of extremes in a risk-based, more geographical explicit manner harnessing recent innovations and improvements in modelling techniques and data.

The climate change modelling community is embracing a more risk-based approach, regional climate modelling as well as climate and socio-economic downscaling techniques are increasingly being utilized; furthermore the climate change community is increasingly linking up with the natural hazards community for modelling natural disaster risk as a function of a geophysical signal, socioeconomic drivers and vulnerability in a stochastic framework accounting for the inherent variability of natural hazards via loss-frequency functions. Such a stochastic representation (cognizant of parameter and modelling uncertainties) of extreme event risks more appropriately reflects the low-probability, high consequence nature of such events. In that manner, this assessment of the costs and benefits of adaptation to climate variability and change as conducted for the DFID ORCHID project for Bangladesh should be understood as an exploration of these issues and with improvements in data and modelling techniques may contribute to planning for helping hazard-prone societies better adapt to climate variability and change.

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