Cost-Benefit analysis of disaster risk reduction

A synthesis for informed decision making

Executive Summary

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Aktion Deutschland Hilft
Germany's Relief Coalition

Acknowledgments

This paper was commissioned and funded by Aktion Deutschland Hilft e.V. – Bündnis deutscher Hilfsorganisationen.

Valuable input was provided by Dr. Markus Moke (Aktion Deutschland Hilft e.V.) and Dr. Jürgen Clemens (German Committee for Disaster Reduction).

Ms. Anne Neumann has provided highly valued support in the finalisation of the paper.

Imprint

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Layout: Medienarchitekten Bonn

Print: www.media-team-huerth.de

Bonn/Brussels, October 2016

Table of contents

Executive Summary

This paper follows the UNISDR terminology on Disaster Risk Reduction (DRR). Terms used in this paper are:

Disaster risk reduction: The concept and practice of reducing disaster risk through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.

Disaster Risk: The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur in a particular community or a society over a specified future time period. In scientific settings disaster risk is usually understood as a function of hazard, exposure and vulnerability.

Disaster: A serious disruption to the functioning of a community or society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

Exposure: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Hazard: A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Recovery: The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.

Resilience: The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Response: The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

1. INTRODUCTION

1.1. Increasing losses

Annual economic losses and fatalities caused by natural disasters are subject to large fluctuations and are strongly linked to extreme events such as the Indian Ocean tsunami in 2004, cyclone Nargis in 2008 or the Haiti earthquake of 2010 (CRED, 2015). However, there is a clear trend of increasing economic and human losses over the last 40 years (Sanghi et al., 2010).

There are several reasons for this trend. Firstly, a rising world population leads to the increased settlement of socially disadvantaged segments of the population in high-risk areas such as riverine flood plains or areas with high probability of landslides. Secondly, human-induced climate change leads to an increased frequency of hydro-metrological extreme events. These combined effects produce a growing number of disasters due to natural hazards (CRED, 2015).

1.2. What is Disaster Risk Reduction (DRR)?

A natural hazard triggers a disaster when it hits vulnerable populations and man-made structures. The disaster risk is a function of the vulnerability of exposed elements and the hazard (see figure 1).

Before the early 19th century, natural disasters were widely accepted as God-given events until this view slowly changed and society identified nature as the source of disasters (Quarantelli, 2000). This hazard-centred perspective triggered an emergence of preventive measures to limit loss and damage from disasters by containing the hazard through physical measures such as dikes or avalanche barriers.

Following this, society began to comprehend that hazards only become disasters if the exposed elements are vulnerable to the impacts of the hazard. Thus, vulnerability became another central aspect of DRR. The vulnerability of impacted elements is a key factor that determines if a natural risk results in a disaster. For example, elderly people usually have fewer capacities to resist the adverse effects of a hazard, and thus are more vulnerable to it. Other determining factors of vulnerability that are commonly cited are educational background, the level of organisation, social and economic standing as well as ethnic background (Wisner et al., 2004; Keating et al., 2014).

The acknowledgement of vulnerability as a determining factor in disaster risk has also influenced DRR projects by governments, NGOs, and international organisations through the addition of "soft" measures of DRR such as disaster preparedness plans, educational measures or early warning systems (Venton & Venton, 2004).

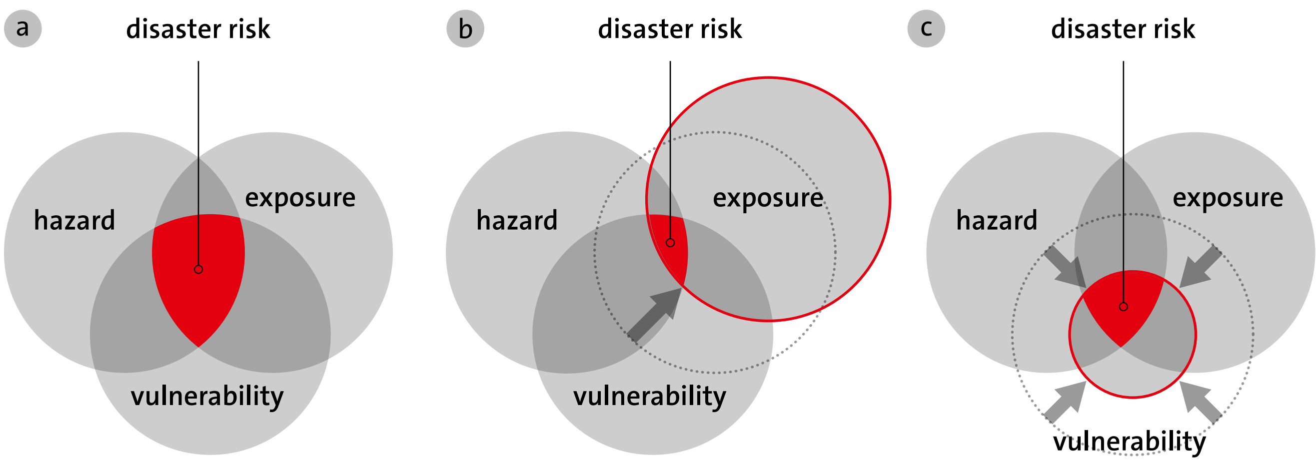

Figure 1: a) Graphical representation of the concept of disaster risk b) Reducing disaster risk by changing the exposure to the hazard c) Reducing disaster risk by minimising vulnerability

1.3. The significance of DRR

The cost-efficient nature of DRR is frequently acknowledged in scientific discourse and political statements. It is seen as a particularly effective way to limit damage and fatalities when compared to response and recovery (Shyam, 2013). For example, the Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) of the European Commission has identified DRR as a key factor in effectively reducing the need for emergency assistance (Dedeurwaerdere, 1998).

The estimation that every one USD invested in DRR saves seven USD in disaster response, allegedly coming from the World Bank, enjoys a certain celebrity status in this context. To this day, this infamous figure is repeatedly quoted in a DRR context:

- "It highlights that every dollar of foreign aid spent on averting and mitigating disasters saves an average of US$7 in humanitarian disaster response." (UNOCHA)[1]
- "A widely cited figure used by the World Bank states that each dollar invested in DRR saves seven dollars in disaster response and reconstruction." (NGO VOICE)[2]
- "Every dollar invested in preparing for natural disasters today can save seven dollars in recovery costs (World Bank)." (OXFAM)[3]
- "The World Bank estimates that every dollar spent on risk reduction saves US$7 in relief and repairs." (Development Initiatives)[4]

Der genaue Ursprung dieser Aussage ist jedoch ungewiss, und die Weltbank selbst hat sich inzwischen von dieser Verhältniszahl distanziert (Shreve & Kelman, 2014).

[1] http://www.unocha.org/top-stories/all-stories/un-launches-video-saving-lives-through-preparedness

[2] http://www.preventionweb.net/files/33631_33631voicedrrn5finallowresolution.pdf

[3] https://www.oxfam.org.au/2015/02/disasters-are-increasing-on-a-global-scale/

[4] http://neo-assets.s3.amazonaws.com/news/Aid_investments_in_disaster_risk_reduction_press_release.doc

1.4. The investment gap

Unfortunately, despite the scientific and political discourse in support of DRR spending, the actual investments in DRR typically do not match the significance attributed to it. Globally, government spending on DRR measures is often limited with the majority of disaster related spending being allocated to response and recovery measures (Benson & Twigg, 2004; Hochrainer-Stigler et al., 2011; Mechler et al., 2014; UNISDR, 2011).

According to an assessment by GFDRR and ODI, between 1991 and 2010, governments, NGOs and international organisations spent a total of 13.5 Billion USD on DRR. The expenditures for recovery and response in the same period totalled 23.3 Billion USD and 69.9 Billion USD, respectively (Kellett & Caravani, 2013).

The literature reports numerous possible reasons for this investment gap in which political considerations play a crucial role. Firstly, DRR projects are often difficult to justify to the public. This is partly due to the fact that the benefits of DRR take shape as avoided damage and remain largely unnoticed by the general public. Meanwhile, generous spending on response and recovery draws considerable public attention (Keating et al., 2014; Vorhies, 2012). Secondly, the positive consequences of DRR usually occur over long time scales, if at all. Politicians, on the other hand, are subject to legislative periods of three to five years which often shifts their focus onto the short-term demands of the general public (Vorhies, 2012; Hochrainer-Stigler et al., 2011). Finally, another common argument is that political decision makers are unable to present sufficient proof of the economic and social benefits provided by DRR.

2. OBJECTIVES AND STRUCTURE OF THE PAPER

2.1. Objective

A substantial number of case studies are available that investigate the efficiency of a huge range DRR measures for all kinds of hazards. However, for two main reasons, it is only partially possible to draw general conclusions from them.

Firstly, the case studies are usually highly contextual (e.g. with regards to the measure, hazards, geographical setting) which limits the transferability of the results. Secondly, the available data is intricate and scattered with widely differing methodologies. Consequently, there is a need for a comprehensive overview of existing case studies as well as a standardised methodological framework to allow for direct comparison between the case studies.

The objective of this paper, commissioned by Aktion Deutschland Hilft e.V., is the development of a structured synthesis of available case studies to create generalised statements about the economic efficiency of DRR. Furthermore, the goal is to present results specifically for different hazard types to allow for a comparison of DRR across all hazards.

This paper provides Aktion Deutschland Hilft e.V. with a robust empirical base, founded on available literature, about the efficiency of DRR. The results can be used to inform politicians, decision makers, donors, and IFIs about potential efficiency benefits of DRR.

This paper does not aim to aggregate the results of the case studies into a "universal" end result (see the abovementioned infamous figure by the World Bank). Such an aggregation, whilst attractive for communicating results to media and the public, cannot be justified from a scientific point of view (Hawley, Moench & Sabbag, 2012; Mechler, 2005; Godschalk et al., 2009). As mentioned above, the highly contextual nature and methodological inconsistency between cases would render such aggregated results as meaningless. The comparison and generalisation of results are thus done with due diligence.

2.2. Structure

Benefit-Analysis (CBA) in a DRR context. The second section establishes a methodological framework which allows for direct comparison of the case studies. We recommend applying this framework for future case studies for improved scientific rigor. The third section presents the results of the assessment of the case studies. The fourth section contains our discussion and our conclusions are presented in section five.

3. THE TOOL CBA IN THE CONTEXT OF DRR

CBA is an appropriate method for the assessment of the economic efficiency of DRR measures. It provides a decision making tool for comparing scenarios with or without DRR in place. A favourable CBA result for a DRR measure can be a strong argument for investment (Ganderton, 2005; UNISDR, 2011). Ideally, it should be used to select the most efficient from a portfolio of projects. Furthermore, CBA is an established and proven tool in public decision-making processes (Chadburn et al., 2010) and in some countries, for example, Germany, it is a statutory requirement (Brockmann et al., 2015).

The Hyogo Framework for Action (UNISDR, 2005) calls for further development and improvement of CBA methods in a DRR context and its increased use in case studies. However, CBA is methodologically complex and should be seen as a decision facilitator rather than the sole criterion for decision making. It should be applied within a wider decision framework that includes social, ecological and cultural concerns (Venton & Venton, 2004; Mechler, 2005; Mechler & The Risk to Resilience Study Team, 2008).

4. METHODOLOGICAL FRAMEWORK

In the following section, we propose a methodological framework for CBA in DRR which outlines the crucial steps in carrying out a CBA. We recommend that this framework is used as an orientation for future case studies. The framework does not require that all steps and methods are thoroughly executed. Rather, it should be seen as a comprehensive outline of steps and methods for consideration when conducting a CBA case study. Crucially, it can be used to identify steps and methods that are not incorporated in the case studies due to methodological difficulties or poor data conditions. This flexible nature makes the framework universally applicable. The steps and methods are listed in the following table and further explained in section three.

Study area, Hazard, and vulnerability	DRR measure and Impact Assessment	Monetary values	Presentation of the results	Uncertainties
Which values are exposed to what risk?	Which measure is implemented and how does it affect the disaster risk?	Which costs and which benefits are considered?	How are the results presented?	How are methodological limitations and poor data conditions handled?
Study area	DRR Strategy	Evaluation type	Presentation of the results (e.g. as cost-benefit-ratio, benefit-cost-ratio, net present value, internal rate of return)	Sources of uncertainties
Hazard	DRR Focus	Value assignment and damage types		Dealing with uncertainties
Hazard Analysis	Impact Assessment	Analysis Period		
Vulnerability Analysis		Discounting		

Figure 2: Steps and methods of CBAs in a DRR context.

5. RESULTS

A total of 117 available case studies from the last two decades (1996 – 2015) were assessed for this paper.

5.1. Study area, hazard and vulnerability

Study area

The case studies vary significantly regarding the extent of the area of investigation and the related level of detail. They range from a small village of a few hundred inhabitants benefiting from a water retention basin for irrigation to 22 EU member states gaining improved dikes.

A CBA needs a clearly defined area for the analysis. Ideally, this area should be defined by administrative borders or by the impact zone of the hazard.

The majority of the case studies were based in South-Asia (India, Bangladesh, Nepal, Pakistan, Sri Lanka and Maldives) as well as South-East –Asia (Indonesia, Philippines, Thailand and Vietnam). There are also a number of case studies Europe (particularly Germany, Austria and Switzerland) and the USA. Sporadic case studies have been found for other European and Asian countries as well as South- and Middle America and Australia/Oceania. With some exceptions in Eastern Africa, no case studies were found for this continent. The map below shows the distribution of case studies and the types of hazards they considered.

Hazard

This paper follows the EM-DAT hazard classification of the Centre for the Research on the Epidemiology of Disasters (CRED)[1] with the addition of two further categories. The first additional category is multi-hazards created to include those case studies which include DRR measures to address a range of hazards. The second category is hydro-meteorological hazards, this category is introduced to incorporate case studies that consider meteorological services including all hydrological, meteorological and climatological hazards.

[1] See http://www.emdat.be/classification

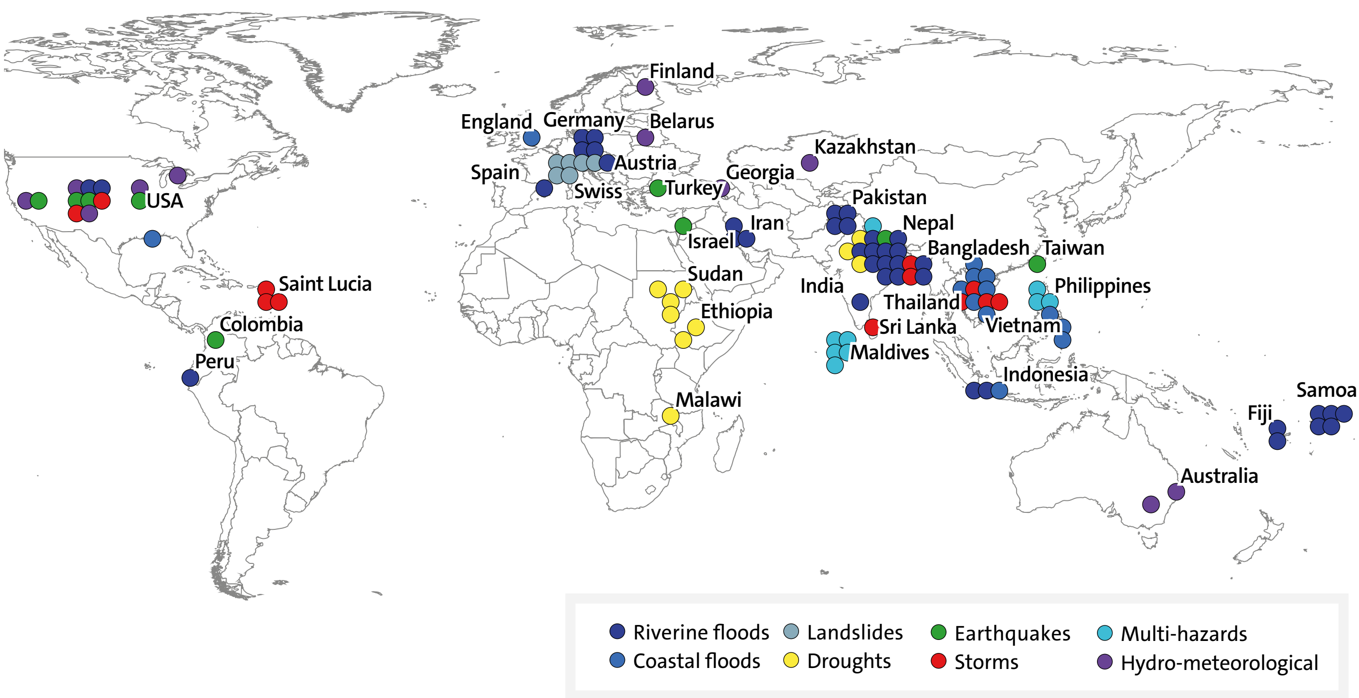

Figure 3: Overview of hazards in the case studies (n=109, case studies with transnational study area are not shown, national studies are mapped in the centre of the respective country, base map changed after http://biogeo.ucdavis.edu/data/world/countries_shp.zip)

As shown in figure 4 case studies were not found for all hazard categories. In fact, many hazards are missing from our data including volcanic activity, extreme temperatures, tsunamis (being a sub-category of earthquakes) and wildfires. Whilst this gap does not suggest that case studies within these categories do not exist it is an indication that case studies are primarily conducted for hazard types and not others.

Figure 4 shows the results[2] of all case studies sorted by hazard category. The individual results for each hazard category are further explained in section 3b.

> CRED defines six groups of natural hazards – geophysical, meteorological, hydrological, climatological, biological and extra-terrestrial. Each of these groups comprises of a number of hazards types and sub-types. Storm, for example is a hazard type in the "meteorological" category and is further divided into tropical storms, extra-tropical storms and convective storms.

Hazard Analysis

Most of the case studies identified only perform a basic hazard analysis, this is often due to poor data conditions resulting in the utilisation of existing secondary data from other projects or statistics from NGOs and governments. In most cases, the source of the data or the survey method is not specified. The most comprehensive data was found almost exclusively in riverine flood case studies which often use official gauge data.

18 case studies collect primary data through field visits and surveys. They usually refer to specific historic events of high magnitude which are retained in the memory of the local communities and where a wide range of data is available. Example case studies utilising this approach include the 2002 Elbe flooding (Förster et al., 2005; Gocht, 2004), the 2004 Indian Ocean tsunami (Venton, Venton & Shaig 2009), the 2007 Cyclone Sidr (Subbiah, Bildan & Narasimhan, 2008) and 2005 Hurricane Katrina.

> The hazard analysis is a central step for CBA in DRR. It determines the intensity and frequency of harmful events within the analysis period. The step defines the requirements of the DRR project and is crucial for the calculation of the expected benefits.
>
> From an economic perspective the implementation of a DRR project only makes sense when there is a sufficiently high risk of potentially harmful events in the analysis period (Mechler & The Risk to Resilience Study Team, 2008).

Vulnerability analysis

The vulnerability of a society depends on a multiplicity of social, economic, political, cultural, institutional and physical factors. Thus the results of the vulnerability analysis are highly site-specific. There is no established

[2] Please refer to section 5.4 for an explanation of benefit-cost-ratios

Geophysical	Earthquake (Ground shaking)	11
Hydrological (61)	Riverine flood	42
	Coastal flood	13
	Landslide (avalanche)	6
Meteorological	Storm (Convective storm, extra-tropical storm)	13
Multihazard	Combination of more than parallel hazards	10
Climatological	Drought	10
Hydro-meteorological	All hydrological, meteorological and climatological hazards combined	12

Figure 4: Count of case studies per hazard (n=117)

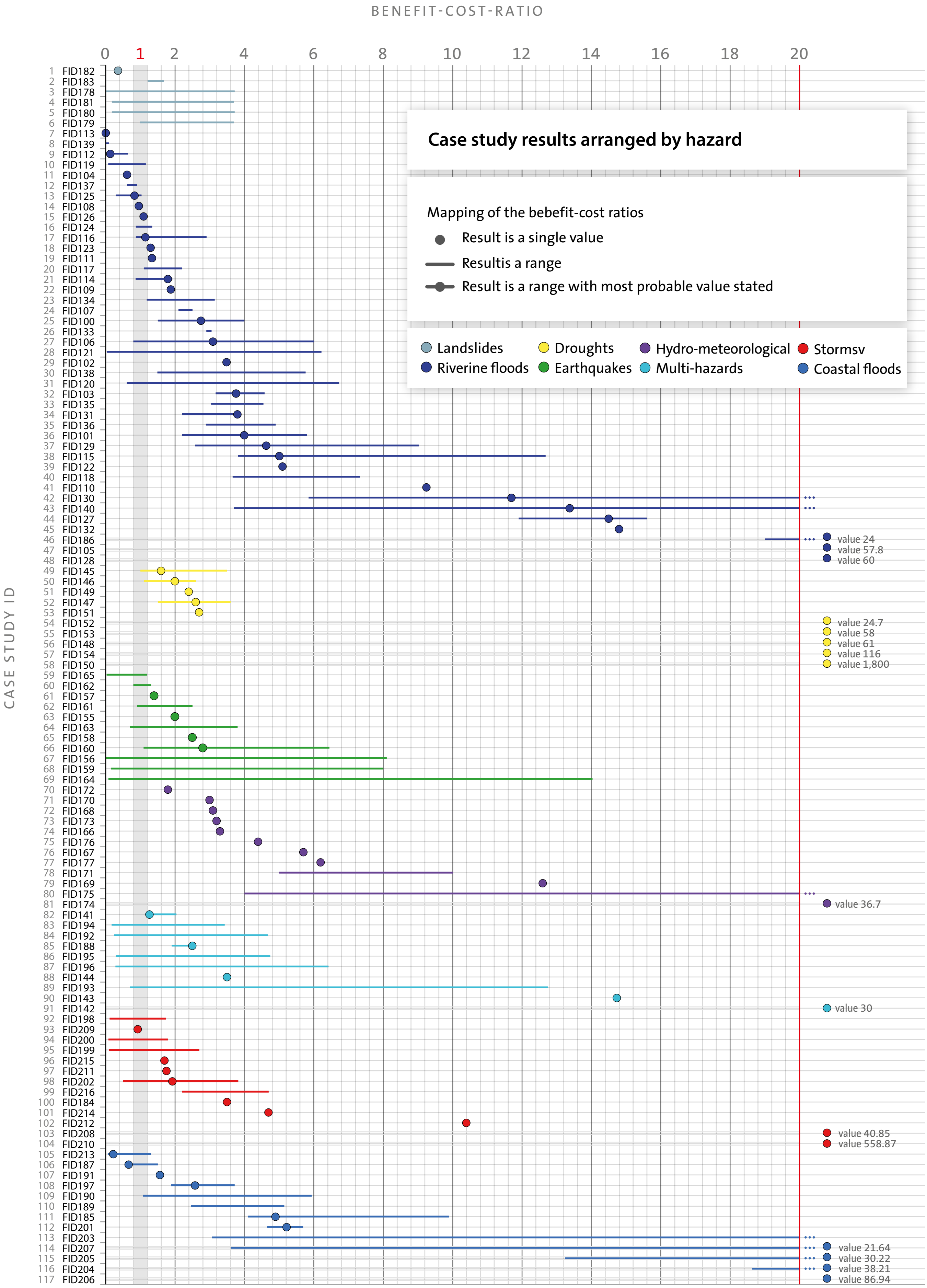

Figure 5: Case study results arranged by hazard (n=117)

or standardised way of conducting vulnerability analysis and the approaches in the case studies vary significantly in extent and scientific quality.

> The vulnerability analysis assesses a at risk in the study area. The objective is to estimate the potential damage generated by the expected hazards in the study area within the analysis period.

5.2. DRR measure and Impact Assessment

DRR Strategy

Of the 117 case studies reviewed in this paper, 65 case studies analyse preparedness measures, 41 analyse prevention measures and only 2 case studies analyse risk transfer studies. The remaining case studies assess a combination of parallel measures that follow different strategies. The prevalence of preparedness case studies is partially explained by a lack of efficient prevention measures to reduce exposure to certain hazard types. For example, earthquake hazard prevention measures would require the separation of the hazard and man-made structures through resettlement.

The results of the case studies (figure 5) suggest that preparedness measures are on average more cost-efficient than prevention measures.

DRR measures can follow three distinct strategies – prevention, preparedness and risk transfer (Mechler & The Risk to Resilience Study Team, 2008). Some examples are given in table 1.

Prevention measures seek to reduce or (as far as possible) avoid exposure by containing hazards and adverse events. Preparedness measures are designed to reduce vulnerability by making arrangements for the impact of hazards. Risk transfer measures transfer and spread risk more widely.

Table 1: DRR strategies

	PREVENTION	PREPAREDNESS	RISK TRANSFER
EFFECT	› Reduce risk	› Reduce risk	› Transfer Risk
KEY MEASURES	› Physical works like dikes (to prevent floods) or irrigation systems (to prevents droughts) › Land-use planning › Economic incentives for pro-active risk management	› Early warning systems › Building codes › Contingency planning › Shelter facilities › Networks for emergency response › Information and education	› (Re-) insurance of public infrastructure and private goods › National and local reserve funds

DRR Focus

The majority (73 of 117) of the case studies reviewed assess structural DRR projects, only 32 case studies explore non-structural measures, and the remaining case studies assess a combination of structural and non-structural measures.

Structural DRR is predominant in most hazard types. Notably, the case studies reviewed concerning hydrologic hazards, coastal flooding and landslides exclusively considered structural measures. However, several studies emphasise the advantages of non-structural measures which usually require fewer resources than structural measures. In fact, a number of case studies investigating riverine floods and storms consider early warning systems to be a very promising non-structural measure (e.g. Subbiah, Bildan & Narasimhan, 2008; Holland, 2008).

One case study of an NGO implementing drought DRR in southern and eastern Africa operated under a limited budget which only allowed for non-structural low-cost measures. These measures included the establishing of self-help groups in Ethiopia (Venton et al., 2013) as well as crop diversification, water conservation, and provision of drought resistant livestock in Malawi (Venton et al., 2010). The CBA results of the measures suggest a very favourable cost-efficiency.

Non-structural measures are predominantly implemented (and analysed) in more recent years particularly following the release of the Hyogo Framework for Action (HFA, 2005). With the exception of four case studies all CBAs of non-structural measures have been conducted after 2008.

The data suggests that non-structural measures are in general more cost-efficient than structural measures. The percentage of non-structural case studies with a benefit-cost-ratio of above 1 is higher. Additionally, the share of non-structural case studies with exceptionally favourable results is higher than for structural case studies.

> Measures can be structural or non-structural. Structural measures are physical constructions that are targeted at reducing the direct adverse effects of hazards. This includes dikes or earthquake resistant buildings. Non-structural measures include knowledge transfer, capacity building and codes/norms. Concrete examples are land use planning and knowledge building in local communities. Early warning systems are also non-structural measures.

Impact Assessment

The benefits of DRR include avoided losses and damages to man-made structures such as buildings, property, machines etc. as well as the avoidance of fatalities, injuries, pain, business interruptions or the loss of or damage to culturally and historically important items (Ganderton, 2005).

> This is to compare the potential impact of an adverse event within the study area with and without DRR in place.

Additionally, DRR projects can have intrinsic value. For example, planting mangroves can be an effective measure to tackle coastal floods (International Federation of Red Cross and Red Crescent Societies, 2011). At the same time, the mangroves can also increase and protect biodiversity, act as a carbon sink and help reduce erosion. Those co-benefits can provide additional arguments in favour of DRR and should be considered in a CBA.

Most DRR projects reviewed target all inhabitants within the study area. The key exceptions are case studies that look at securing schools against effects of earthquakes (Chiu, Hsiao & Jean, 2013; Kunreuther et al., 2012; Valcárel et al., 2013) or those DRR measures to mitigate the effects of drought specifically for the semi-nomadic Beja (Khogali & Zewdu, 2009; International Federation of Red Cross and Red Crescent Societies, 2009b; International Federation of Red Cross and Red Crescent Societies, 2012).

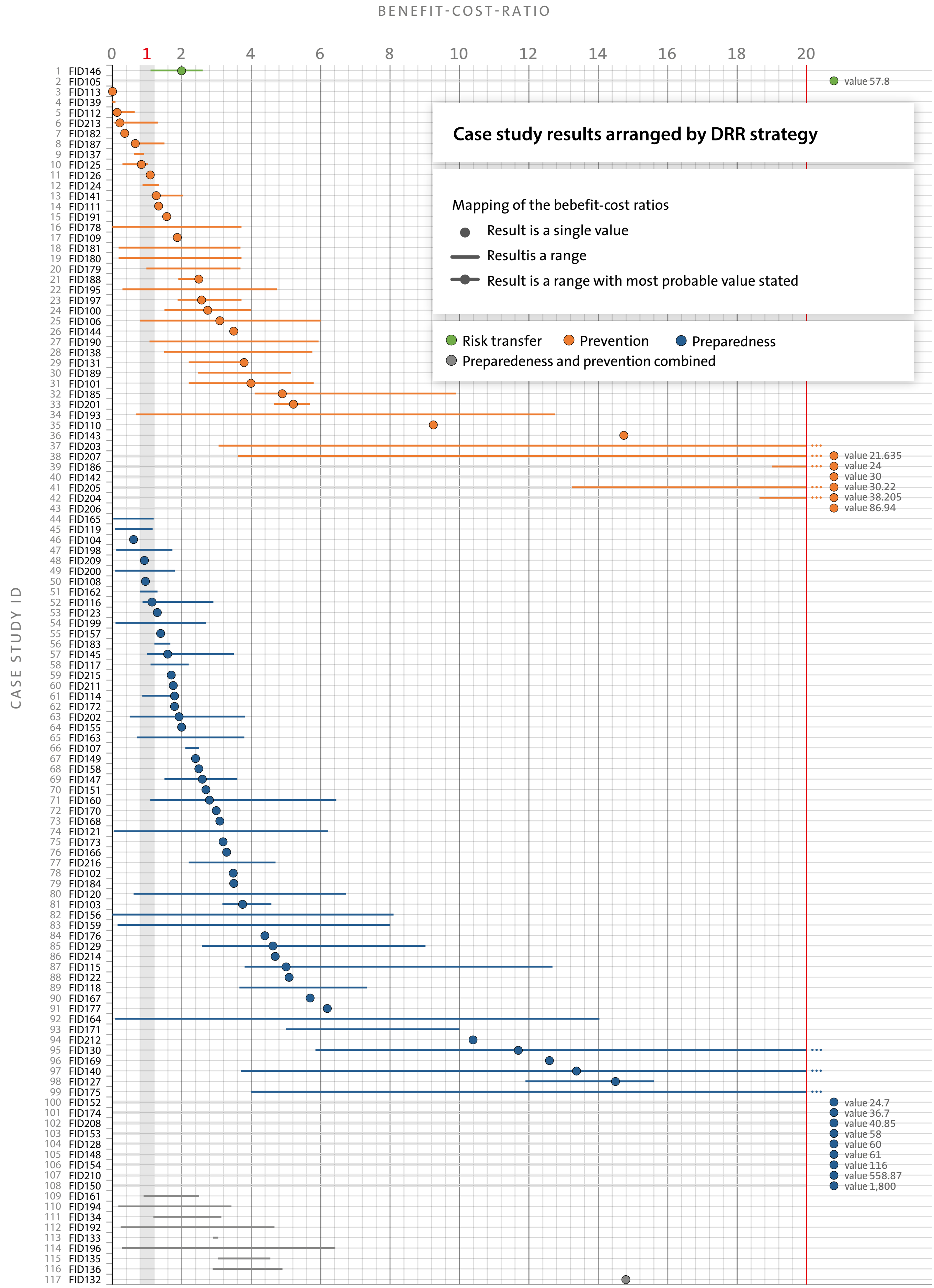

Figure 6: Case study results arranged by DRR strategy (n=117)

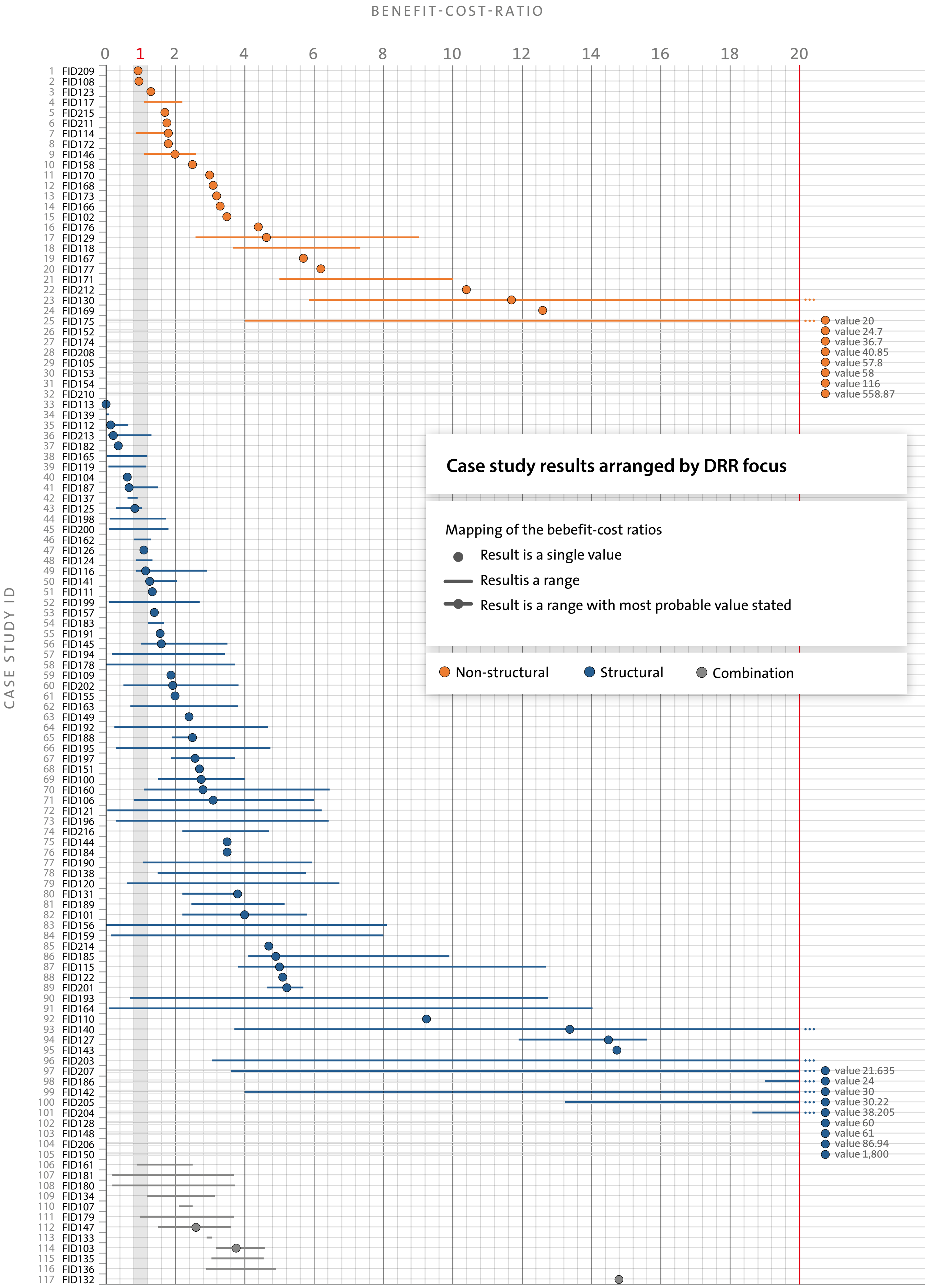

Figure 7: Case study results arranged by DRR focus (n=117)

5.3. Monetary values

Evaluation type

Figure 7 shows the results of the case studies sorted by evaluation type. In total, there are 77 ex-ante case studies and 21 ex-post case studies. Combined case studies are not displayed.

Ex-ante case studies generally display a wider range of uncertainty. There is also a weak indication in the data that DRR in ex-ante case studies perform better than in ex-post case studies.

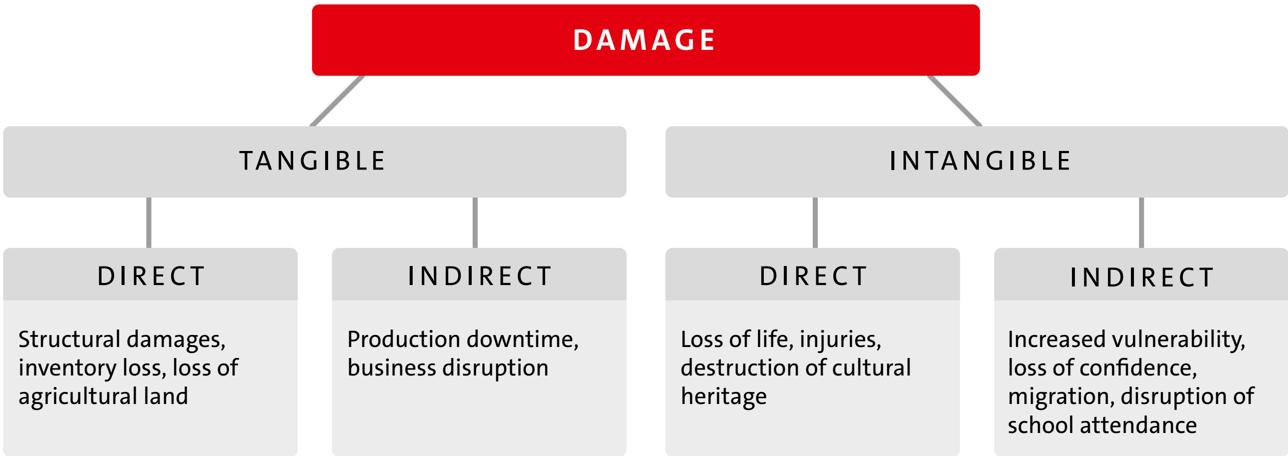

Figure 8: schematic representation of damage categories

For a CBA, both costs and benefits need to be expressed as monetary values. The costs are the expenses that accrue for the DRR implantation (e.g. construction and staff expenses).
The benefits are the sum of avoided damages through the use of DRR measures. There are different categories of damages. Damages are tangible when they have a market value (e.g. construction material, equipment, services or farmland). Intangible damages, on the other hand, don't have a direct market value i.e. they cannot be bought. This includes social damages including fatalities, injuries, increased vulnerability, traumata, or feeling insecure. It also includes other damages such as loss of biodiversity and habitats. The process of assessing intangible damages and assigning monetary values in order to incorporate them into the CBA is usually complex.

Additionally, damages can be direct or indirect. Direct damages are an immediate consequence of the disaster such as fatalities or damage to buildings. Indirect damages, on the other hand, are highly elusive and result from the aftermath of the disaster, such as production downtimes or migration (Kousky, 2012).

Value assignment and damage types

In the case studies for structural DRR, unsurprisingly, the expenditures are predominantly defined by the construction costs. For non-structural measures, the costs that are most frequently assessed are staff expenses, material, and production costs.

In the studies reviewed, the most frequently assessed direct tangible damages relate to buildings, agricultural areas, equipment, and infrastructure. The most commonly assessed indirect tangible damages include business interruptions and loss of income. The value of these indirect tangible damages can be significant. For example, a study by Padgett, Dennemann & Gosh (2010) on an earthquake resistant bridge in Missouri, USA concluded that, if the bridge was destroyed, the indirect tangible damages accrued through longer alternative driving routes could be 5-20 times higher than the direct tangible damages.

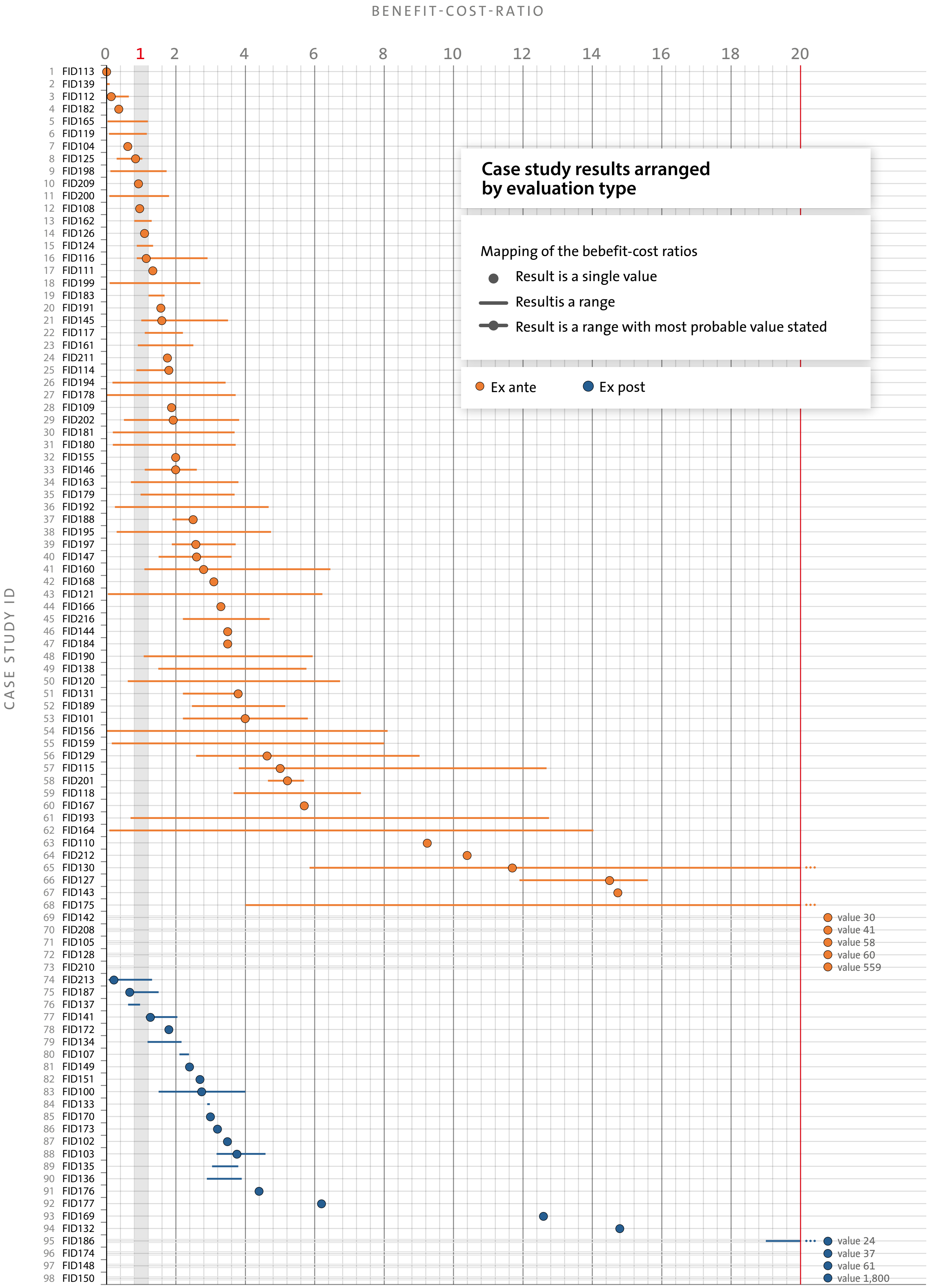

Figure 9: Case study results arranged by evaluation type (n=98, combined case studies are not displayed)

In the cases reviewed for this study, intangible damages were often unassessed. The category incorporated most frequently (n=26) was human life. This is commonly assessed using the individual's foregone earning capacity (by estimating future income) and the willingness-to-pay approach. Values vary considerably between cases, ranging from 35.000 USD (Hallegatte, 2012) to 6.000.000 USD (Kunreuther et al., 2012; Hochrainer-Stiegler et al., 2011). A significantly higher number of structural case studies (twice the number than those of non-structural studies) assigned a monetary value to human life. In some cases, study results only produced efficient DRR cost ratios if human lives were factored in.

A contentious point in DRR CBA is assigning a value to human life (including injuries, traumata or deaths). This is because in addition to the methodological complexity, there are also ethical concerns (Mechler & The Risk to Resilience Study Team, 2008; Benson & Twigg, 2004; Cropper & Sahin, 2009).

Analysis Period

Analysis periods ranged between 7-90 years, with the majority of cases falling between 35-50 years. Some case studies (n=14) did not state an analysis period.

Results showed that analysis periods used for DRR in North America and Europe were longer than those in African, or Southern and South-Eastern Asian studies (see figure 8).

The data also suggested that the analysis periods in ex-ante case studies were on average longer than those used in ex-post case studies.

Analysis periods ranged between 7-90 years, with the majority of cases falling between 35-50 years. Some case studies (n=14) did not state an analysis period. Results showed that analysis periods used for DRR in North America and Europe were longer than those in African, or Southern and South-Eastern Asian studies. The data also suggested that the analysis periods in ex-ante case studies were on average longer than those used in ex-post case studies.

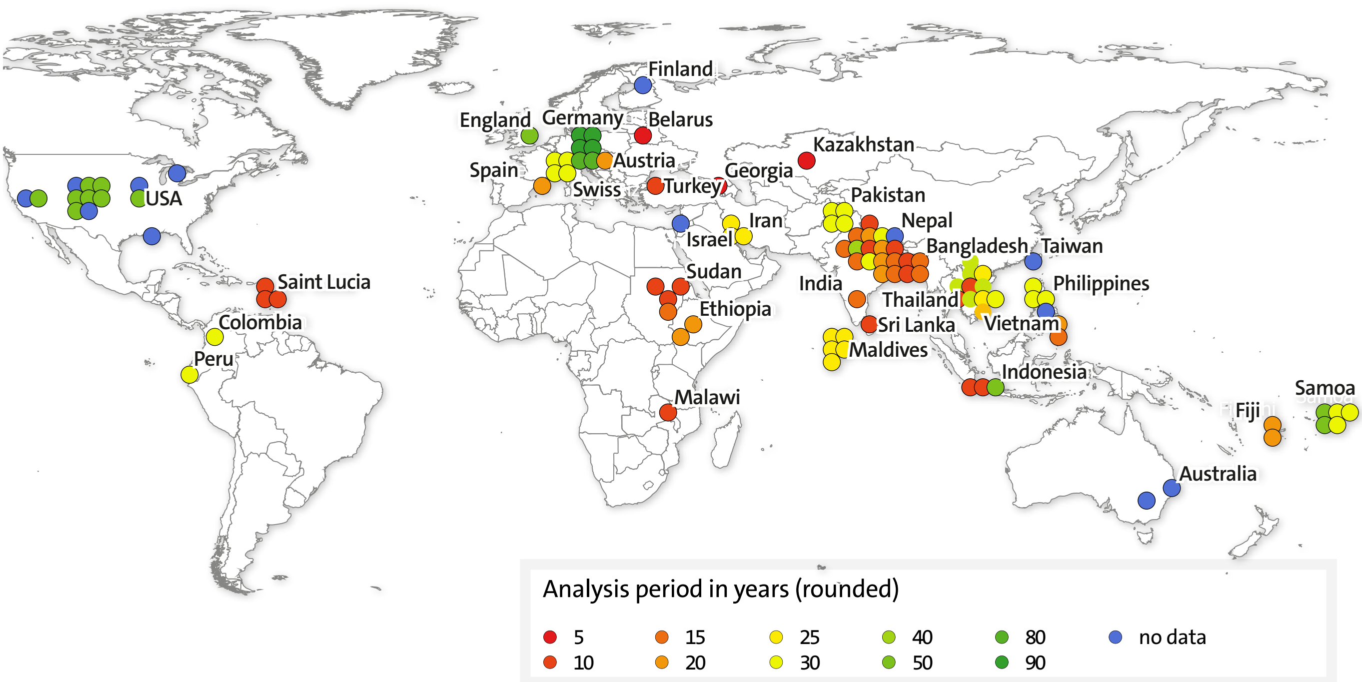

Figure 10: Overview of analysis periods in the case studies (n=109, case studies with transnational study area are not shown, national studies are mapped in the centre of the respective country, base map changed after http://biogeo.ucdavis.edu/data/world/countries_shp.zip)

In most instances the analysis period is defined by the timeframe in which the DRR (or its longest living part) delivers benefits. For example, in the structural measures this could be defined by the productive lifespan of the structural elements. When referring to non-structural DRR timeframes, this could be determined by the decreasing impact of training sessions.

Another approach is to use the project length as a proxy for the analysis period. However, the benefits generated by DRR generally accrue for considerably longer periods than the project length.

Discounting

Discount rates were applied in 98 of the case studies and ranged from 1.3% - 20%. The majority of cases (n=69) used rates between the range of 7% and 12%.

In most cases, the discount rates applied in Europe and North America were considerably lower than those used in Latin America, South and South-East Asia, and Africa.

Discounting refers to the process of assigning a lower weight to a unit of benefit or cost in the future than to that unit now. In discounting, we place a higher value on the present than the future.
Typically, CBAs take account of this time preference by applying a discount rate over the costs and benefits over the analysis period. The further into the future the benefit or cost occurs, the lower the weight attached to it (Pearce, 2006).

5.4. Presentation of the results

The expected benefit-cost-ratios are in 102 of the 117 above the value of one – i.e. 102 case studies expect that the benefits of the assessed DRR surmount the costs. This can be seen as a strong argument to allocate more money to DRR in this period of limited public resources. The results are presented separately for each hazard in section 6.

The cost-benefit-ratio is determined by dividing the DRR costs through the DRR benefits. The result is presented as a ratio (such as 1:10 or 1:2) like on map scales. A project is considered efficient if the divisor is bigger than one (i.e. when the benefits are higher than the costs).

Fairly often the result is also stated as benefit-cost-ratio for which the benefits are divided through the costs. In this way of representing the results a project is efficient when the result is above one. In this paper we use the benefit-cost-ratio to present the results.

There are other ways of presenting the results like the net present value or the internal rate of return.

5.5. Sources of uncertainty

> In conducting a CBA for DRR there are a number of sources of uncertainty which include poor data conditions, the assessment and monetarisation of vulnerable values (especially for intangible and indirect values) or the application of a discount. There are no agreed standards on which discount rate to choose even though it can potentially have a big impact on the final result. The same applies for the determination of the analysis period.

Most steps in CBA are prone to uncertainties and it is essential that authors highlight those sources of uncertainties appropriately in the case studies (Forni, 2014). It should also be described how each of these uncertainties have been dealt with, respectively.

82 of the 117 case studies perform a sensitivity analysis. The majority of them (54 case studies) varied the discount rate followed by altering assumptions in the hazard analysis (39 case studies). Assumptions made for assessing costs and benefits are varied in around 30 case studies. Some authors (17 case studies) also varied the analysis period.

Only 21 case studies take into account possible impacts of climate change (seven riverine flood, five multi-hazard, four storm flood and drought as well as one storm case study).

> In order to take into account the uncertainties inherent in CBA a last step of the CBA should be preforming a sensitivity analysis. In a sensitivity analysis the author varies a number of parameters (one at a time) along their range of credible specifications to assess their impact on the final result.
>
> A well performed sensitivity analysis allows the author to test the robustness of the results (Woodruff, 2008; Tuan & Tinh, 2013).

6. RESULTS PER HAZARD

6.1. Introduction

This section positions the general results of the previous sections in their specific hazard context and thus providing a more nuanced picture of the efficiency of DRR for the analysed hazards.

For some hazards, the sample size is very limited whilst in other cases, there is a large body of literature to draw upon.

6.2. Landslides

Case studies exploring landslidess were limited (n=6) therefore, generalisations of the results should be treated with caution. All case studies reviewed in this work reveal a ratio of benefits and costs which are close to or even below the economic equilibrium. However, it is pertinent to highlight that all case studies concerning this hazard were located the Swiss and Austrian Alps. These locations generally already benefit from a high degree of protection. Consequently, additional protection measures are increasingly costly and raising the protection status is often associated with a low overall gain.

The six case studies suggest that mass movement DRR is inefficient with associated costs exceeding expected benefits. However, this assumption is only valid for the aforementioned study areas and the specific prevention measures which have been analysed. It is surprising that we were unable to locate additional literature referring to cost-benefit studies in other mountainous regions around the world.

> The mass movement category includes hazards such as avalanches, rockfall, mudflow and debris flow, all of which are downhill shifts of surface material being moved by gravitational force.

6.3. Riverine floods

Case study literature availability was highest for the hazard type of riverine floods (see Figure 10).

Of the 41 case studies reviewed, 9 had ratios which were below the economic equilibrium (bold verticla line). Of

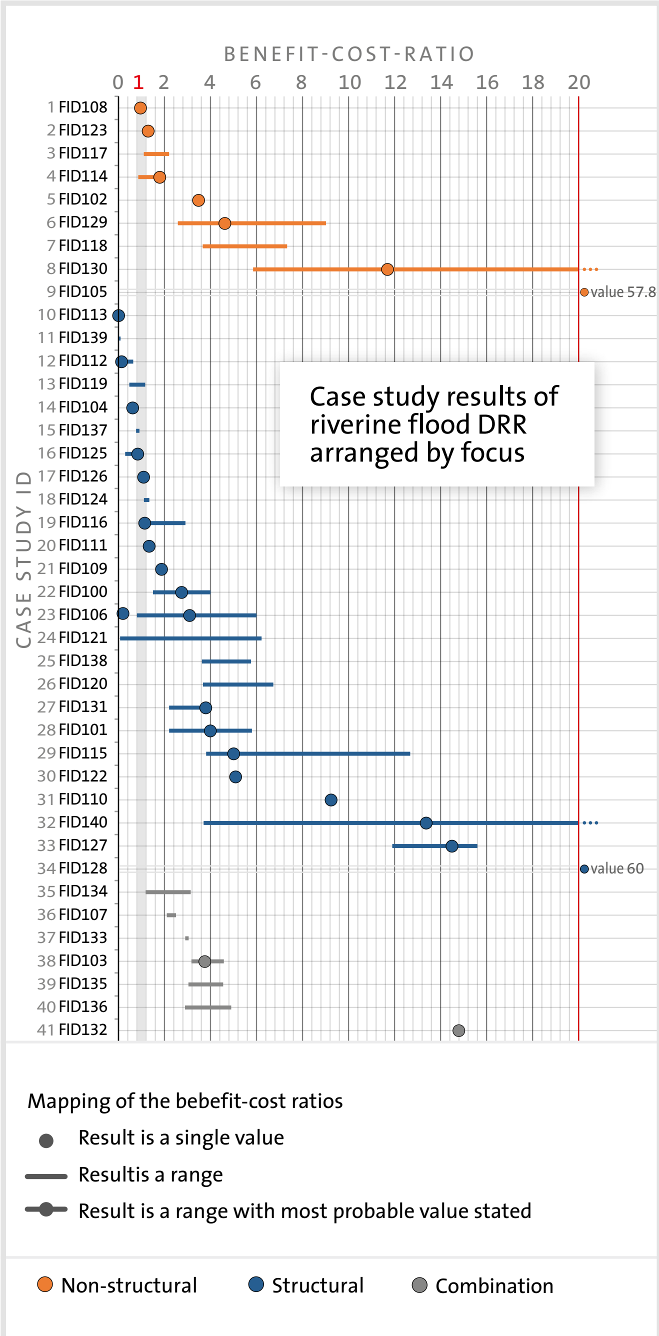

Figure 11: Case study results of riverine flood DRR arranged by focus (n=41, in ascending order)

those case studies performing below the economic equilibrium, 8 had a structural focus whilst only one non-structural measure was not proven to be economically efficient.

Structural measures can include large infrastructural projects such as construction and strengthening of dykes and polders, redirection of river channels, the raising of buildings, and the construction of highly resistant buildings. Most non-structural measures can be summarised under the header of early-warning systems. Usually, non-structural measures are applicable for protecting against a wide range of threats. They are also usable in situations not directly linked to DRR, as a result, non-structural measures are often more robust and can usually be realised with lower costs compared to their structural counterparts.

Riverine floods (floods along rivers) are is that hazard that triggers disasters most frequently.

6.4. Droughts

The results of the available drought case studies vary greatly. Whilst some case studies (n=2) are just above the economic equilibrium other case studies in this category report results which are among the economically most advantageous across all hazard categories (n=5). The results of the drought case studies point overall in the direction of high economic efficiency. This case study research suggests that drought DRR has proven to be cost efficient over a number of measures and therefore offers a promising outlook.

Result interpretation suggests higher efficiency in non-structural DRR measures than in structural ones. Even under very optimistic circumstances a benefit-cost ratio above four was not achieved through structural measures (e.g. construction of wells, pumps, and dams). However, non-structural measures were reported to be highly cost efficient. Measures such as training and education, diversification of agriculture, provision of seeds and foundation of disaster management committees as well as the (structural) construction of community gardens report a consistent benefit-cost ratio above 25.

Droughts are a creeping hazard. They are usually defined as a lack of rain over a defined time or the absence of rain over specific, location-depended, periods.

6.5. Earthquakes (ground shaking)

From a purely economic standpoint, earthquake (ground shaking) DRR is difficult to justify. Compared to other hazards, earthquakes ranked lowest. Of the case studies reviewed (n=11), the majority of cases (n=9) performed at a level that was either close to the economic equilibrium or contained parts of the measurement range which were considerably below a benefit-cost ratio of one. Additionally, there was minimal improvement in the economic performance even where avoided fatalities were monetarized and included as a benefit.

Earthquakes are caused by the movement of tectonic plates. Their geographic domain can be determined fairly accurately. On the other hand, the determination of reoccurrence rates is very challenging.

Throughout the world, earthquakes are the hazard responsible for most fatalities – however, this number also includes fatalities from earthquake triggered tsunamis. This section only considers DRR measures to reduce impact of earthquake related ground shaking.

6.6. Hydro-meteorological hazards

All case studies focused on the setup and enhancement of hydro-meteorological services (n=12) report benefit-cost ratios of above one. Indeed, in most cases, the value is far above the economic equilibrium with the majority of results ranging between three and six. Consequently, we determine that it is worthwhile to invest in such measures. The improvement of hydro-meteorological services is particularly worthwhile in countries with a high human development index[3], such as the U.S., Australia, and Finland. This is in contrast to the general observation that the efficiency of DRR in countries with high HDI scores is on average lower than in countries with a low human development.

Despite these highly performing cases, none of the studies reviewed included a consideration of present or future climate change threats. Since climate change is expected to alter hydro-meteorological patterns and increase the frequency of extreme events (extreme rainfall or no rainfall over long periods of time) the incorporation of these threats into cost-benefit ratios would likely yield even higher results.

[3] In this study the development status or state of development is defined by the human development index (HDI): http://hdr.undp.org/en/content/human-development-index-hdi

> The category of hydro-meteorological hazards is introduced to describe case studies that consider meteorological services. These services provide predictions for meteorological and hydrological extreme events and can also be used to extrapolate climatological trends.
> This category comprises all hydrological, meteorological and climatological hazards.

6.7. Multi-hazards

Although the literature stresses the value of DRR measures which are applicable across a range of potential hazards, this sentiment is not reflected in the case studies reviewed. This review located a rather limited number of cases on multi-hazards (n=10) and of those cases, half had value ranges that stretched below the economic equilibrium. This may be linked to the increase in uncertainties and complexities which occur when multiple hazards are considered in combination. For analysis of these measures, each individual hazard plus the interconnectedness of the hazards must be assessed. Nonetheless, all case studies result in average ratios which are above the economic equilibrium. This is a promising result and can be used as justification for support of further research on the economic efficiency of multi-hazard DRR measures.

> Multi-hazard case studies assess those hazards which as deemed to be spatially overlapping or those hazards identified as interrelated. Hazards found in this category may be triggers for other hazard types.

6.8. Storms

Case studies addressing storm-related DRR (n=13) generally performed well, only one study reported a benefit-cost ratio below the economic equilibrium and a limited number (n=4) reported a range close to one. A number of studies (n=3) reported very promising benefit-cost ratios with one study reporting a ratio of above 500. Results of the analysis varied with some case studies close to one and others well above the economic equilibrium. Generally speaking, the results are promising and point towards cost effectiveness of DRR against storms.

> Storms are meteorological events. They are the hazard responsible for the highest damage globally.

6.9. Coastal floods

Many of the coastal floods case studies extracted (n=13) for this review performed well. A number of studies report ratios significantly above the economic equilibrium, and only two case studies reported benefit-cost ratios (either individual measurement points or a value range) of below one. All case studies analysed measures were structural in nature and focused on prevention strategies.

Coastal floods are triggered by strong onshore winds. Either extra-tropical storms or tropical cyclones push water in the direction of the coastline potentially leading to coastal inundation.

7. DISCUSSION

7.1. Study area, hazard and vulnerability

Literature suggests that DRR has greater cost efficiency in countries with a low HDI score. This imbalance may be due to highly concentrated populations within these countries (Ganderton, 2005). Additionally, it may be linked to, the greater macroeconomic damage caused by natural hazards relative to the gross domestic product in countries with low HDI scores. In highly developed, industrialised countries, macroeconomic damage relative to the gross domestic product is generally low (Keating et al. 2014).

> Although it is hard to assess which underlying factors cause this trend, plotting the results of all 117 cost-benefit analysis against the HDI of each country reveals a trend of rising cost effectiveness of measures to reduce disaster risk in those countries with lower HDI scores which suggests that DRR is, on average, more successful in countries with a lower HDI.

Results of this analysis suggest a limited range in the focus of cost-effectiveness studies, with the majority of case studies reviewed focusing on riverine floods. Whilst we accept that riverine flooding research is the hazard which impacts the largest proportion of people worldwide (2.5 billion or 55 % of all people affected between 1994 and 2013) and would, therefore, expect it to feature significantly in the literature. There are other hazards, such as earthquakes or storms, which have greater implications for casualties than riverine flooding hazards (CRED, 2015), as a result of the seriousness of these impacts, we had expected to identify more of these DRR case studies. For other hazards such as tsunamis and forest fires, we were unable to locate any case studies. Whilst this paper is unlikely to have captured all available literature, we conclude that current research is heavily focused on a limited number of hazards and we recommend that future research efforts be focused on expanding case studies to address a broader range of hazards.

In considering the economic cost effectiveness of DRR, the results of this analysis determines that DRR prevention measures in droughts and hydro-meteorological hazard events are cost effective. However, for all other hazards reviewed in this study, we did not find economic efficiency in all case studies observed. In some cases, the economic input is sometimes not offset by the potential or actual economic savings generated by the preventive measure. These results do not imply that we should reject disaster prevention measures altogether, as preventive measures are often ethically justifiable and may be required by mandate in some countries.

7.2. DRR measure and Impact Assessment

There are substantially more structural prevention measures described in the literature which may suggest an increased number of these measures on the ground. We attribute this to three related factors; firstly, from a methodological standpoint, it is harder to assess the benefit of non-structural measures. Secondly, it can be difficult to attribute positive outcomes directly or indirectly linked to a prevention measure, particularly as the most successful prevention measures will result in complete disaster avoidance. Finally, the line between non-structural disaster prevention measures and general measures to enhance the livelihood or knowledge base of a community or society are often overlapping making it difficult to distinguish between the two goals. For example, an education program to improve access to the local labour market may provide disaster prevention through enhancing community resilience towards external stressors such as natural hazards.

Nonetheless one should not conclude that the presence of fewer case studies is a sign that fewer non-structural DRR measures are being implemented in practice.

We found promising outcomes for DRR CBA in non-structural DRR measures particularly for droughts and hydro-meteorological hazards. Furthermore, this study found that droughts and hydro-meteorological events had the most efficient cost ratios of cases reviewed, which may point to a link between improved performance and the utilisation of non-structural measures. This suggests that there is untapped potential in pursuing the use of non-structural measures across other hazard categories. Moreover, non-structural measures are more flexible and adaptable when compared with structural measures (Keating et al., 2014; Van Niekerk et al., 2013). As a result, we recommend the use of non-structural measures in cases where substantial uncertainty exists within the hazard analysis.

7.3. Monetary values

The results of ex-post case studies are usually characterised by a large margin of uncertainty. Additionally, we might interpret the (hypothetical) cost-benefit success of ex-ante case studies as an intrinsic element of such case studies in that they overestimate the success of a measure before it is actually realised. The same is true for the project lifetime. On average, we found substantially longer project lifetimes in studies of ex-ante risk reduction measures.

We acknowledge that the assessment of intangible and indirect damages presents substantial uncertainties and methodological challenges, often resulting in them being omitted from the assessment. On the contrary, it is relatively simple to reliably quantify the direct costs of implementing a DRR measure. This gap in the ability to calculate costs and benefits suggests that the 'real' value of DRR measures is systematically underestimated resulting in imbalanced cost-benefit ratios (Vorhies, 2012; Woodruff, 2008). Some studies go one step further stating that prevented intangible and indirect damages are considerably higher than damages which can be easily quantified in monetary terms (Dedeurwaerdere, 1998; UNISDR, 2011).

The timeframe over which cost and benefits are analysed has a substantial influence on the overall result of the cost-benefit analysis. This has particularly important implications for the discounting rate and the degree of uncertainty. Firstly, discounting over long timeframes can lower the economic value of a DRR measures. Secondly, the inherent uncertainties of the cost-benefit analysis increase alongside longer timeframes (Kull, Mechler & Hochrainer-Stiegler, 2013). Hence, a reasonable timeframe is of utmost importance in accurate analysis, however, the determination of this criteria is lacking in scientific rigour.

The same lack of rigour is also present in defining reasonable discount rates, which despite their substantial influence on the final result, have no standardised guidelines.

7.4. Presentation of the results

In addition to the cost-benefit ratio, there are other mathematical concepts to evaluate costs and benefits. The most frequently used of these alternative methods are the net present value and the internal rate of return. All three methods assess the economic profitability of DRR measures. Any of the three methods is equally appropriate for assessing whether the benefits exceed the costs for any DRR measure. Nonetheless, to retain compatibility between results, this study focuses on case studies which report the economic profitability in the form of a cost-benefit ratio.

It is desirable to define one method of presenting results which any cost-benefit case study should fulfil. Indeed, some case studies report more than one method to enable the comparison with other case studies (see e.g. Mechler & The Risk to Resilience Study Team, 2008).

7.5. Sources of uncertainty

CBA is a powerful tool to assess the economic efficiency of DRR. Nonetheless, as outlined above, the results should be treated with caution because methodological nuances have a substantial influence on the overall procedure to assess cost and benefits. To effectively utilise the results methods should be explicitly outlined alongside a transparent overview of any data processing.

We consider the following points to be essential in addressing methodological uncertainties:

- Highlight sources of uncertainty;
- State reasons for all assumptions made;
- Express all types of damage which have not been included in the analysis and the reasons for the exclusion; and
- Conduct a sensitivity analysis.

These points provide the reader with the necessary tools to interpret the results correctly and help avoid the assumption that the CBA results are set in stone.

DRR targeting extreme natural hazards is usually associated with high investment costs and large uncertainties about future hazard occurrence. However, many societies live with high frequency and low magnitude events which constantly erode livelihoods and inhibit economic progress (Moench & The Risk to Resilience Study Team, 2008). Our results determine that focusing on these low frequency and high impact events might yield highly (economic) efficient disaster prevention measures, particularly in regions with a low human development index. Due to the limited prevention measures currently in place, new implementations can create substantial benefits and encourage sustainable development in the region (Hoang Tri, Adger & Kelly, 1998; Subbiah, Bildan & Narasimhan, 2008).

8. CONCLUSIONS

This paper has analysed 117 case studies and provides a comprehensive overview of DRR efficiency. Structuring the case studies along a consistent methodological framework allows a comparison of the results and their assumptions across all case studies and allows us to draw general statements concerning the cost efficiency of disaster prevention measures.

The key results are summarised below:

- **DRR pays off** – Based on 117 case studies, 102 report average cost-benefit ratios above the economic equilibrium. This is a powerful argument for future investments in disaster prevention.

- **Non-structural measures are on average more cost efficient than their structural counterparts** – A greater proportion of structural measures fail to reach the economic equilibrium. Half of all structural measures (n=34) are either within their lower uncertainty margin or below the economic equilibrium. This result was significantly lower for the non-structural measures (n=3 out of a total of 32). We believe that non-structural measures are more flexible and robust in addressing future DRR uncertainties.

- **DRR prevention and preparedness strategies are equally efficient** - Based on all 117 case studies no discernible trend preferring either prevention or preparedness measures is visible.

- **The lower the HDI of a country the higher the economic gain of DRR measures** - On average there is a higher gain from DRR measures in countries with a low HDI compared to highly developed nations. This is a powerful argument for the expansion of DRR measures in world's poorest countries. The significance of this result is enhanced if we consider that in the past, case studies utilised high discounting and assumed low durations of effect in these countries. However, countries with a low human development index are underrepresented in the case studies.

- **Ex-ante evaluations usually assume longer DRR lifecycles and calculate higher benefit-cost ratios in comparison with ex-post evaluations** - On average, ex-ante evaluations estimate a higher efficiency of DRR than ex-post evaluations. Or conversely, ex-post evaluations may systematically underestimate the benefits of a disaster prevention measure. We also found shorter durations of effect (on average) in ex-post analyses. Unfortunately, we were unable to locate a study which compared the two evaluation techniques across a single case. This represents an empirical research gap and hinders the ability to validate the methodological consistency of cost-benefit analyses.

- **The CBA results could be influenced by the entity conducting the study** - We divided the analysed case studies according to the contracting authority. Usually, relief organisations and independent research institutions (i.e. think tanks) conduct the cost-benefit analysis themselves. This can lead to results bias resulting in higher benefit-cost ratios compared to results from university research published in the peer-reviewed literature.

- **The estimated DRR lifetime is on average considerably lower in countries with a low HDI than in countries with a high HDI** - There are substantial differences in the average expected DRR lifetime between countries with a low HDI and those with a high HDI. The DRR lifetime is likely influenced by the type of the implemented measure. As a result, we may observe lower lifetimes on DRR measures where low HDI countries lack the resources to invest in long-lasting, large-scale DRR measures.

This paper presents a methodological framework for a structured analysis and cross-project comparability of economic efficiency in DRR. This framework may be used to conduct future cost-benefit analyses to enhance the significance of future case studies and underpin the value of DRR by applied research. In considering the next steps, there is a substantial short-term need to conduct additional case studies based on rigorous scientific standards. In the long-term, we recommend the creation of a worldwide result database of CBA in DRR. A database would improve predictability of DRR efficiency based on certain characteristics such as DRR project type, study area, hazard, focus, strategy etc. The EM-DAT database for disasters could be used as a reference.

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