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Ensuring Sustainable Development within a Changing Climate

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PhD thesis

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Ensuring Sustainable Development within a Changing Climate



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Submitted: September 2010

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Preface

The main motivation for writing this thesis is a profound interest in development and climate change research. The question of how to address the impacts from climate change to development is a challenging and important area of theoretical and applied research. The aim of the four individual papers in the Ph.D. thesis is to address this aspect from different angles. The emphasis is on how climate change impacts will influence on rural livelihoods, as well as on already existing and on-going development programmes, projects and planning efforts. Additionally, it is explored how adaptation to climate change can be considered in the context of general development efforts in order to ensure sustainable development paths.

With my background in agricultural economics, the thesis is the result of a blend of economics and the study of humans interface with nature. This is exposed in the different forms and approaches that the papers presented in the thesis take.

The Ph.D. thesis has been prepared under Institute of Geography and Geology at University of Copenhagen and funded by the UNEP Risø Centre on Energy, Climate and Sustainable Development (URC) at Risø DTU, where I have been situated for quite a number of years.

Throughout the long process of writing the Ph.D. thesis, a large number of people have helped and supported in many ways. The list is by no means inclusive, though I would like to particularly thank the supervisors of the Ph.D. project Ole Mertz at Institute of Geography and Geology, and Kirsten Halsnæs at DTU Climate Centre, for helping me to frame the questions and for valuable comments and suggestions. I am also thankful to John Christensen, head of URC, for giving me the opportunity to write this thesis.

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1. Introduction

Climate change presents a new type of challenge for development. It is by now widely acknowledged that climate-change impacts amplify existing unfavorable conditions for developing countries (McCarthy et al. 2001). It is also acknowledged that poor populations are more vulnerable and have less adaptive capacity to confront such changes (Swart et al. 2003). Countries with a lack of resources, poor infrastructure, and unstable institutions have little capacity to adapt and are highly vulnerable (Smit and Pilifosova 2001). These factors are intrinsically linked with those promoting sustainable development that aims to improve living conditions and access to resources. Therefore, development planning and strategies have an important role in strengthening the adaptive capacities of societies at various levels.

Adverse effects of climate change are determined not only by the changing climate but also by the sensitivity of human and natural systems to these changes. The need for human (and natural) systems to adapt to changes in climate is not new, and humans are not powerless victims in response to changes and risks (Scoones et al. 1996; Christoplos et al. 2001; Roncoli et al. 2001). Climate variability and droughts are already important stress factors in Africa, where rural households have adapted to such factors for decades (Mortimore and Adams 2001; Mertz et al. 2009), and in extreme dry regions households have even moved 'beyond climate' dependence (Nielsen and Reenberg 2010). Thomas et al. (2007) found that dry spells cause farmers to shift away from cropping to livestock holding. In Mali, Lacy et al. (2006) revealed a tendency for a shortening of the rainy season to induce farmers to shift some of their sorghum production to a variety with a shorter cycle than the traditional one. In a study from Burkina Faso, Nielsen and Reenberg (2010) found rain-fed cereal production to be declining due to a change in climate and a shift towards a higher level of dependence on migration, livestock, small-scale commerce and gardens. In East Africa, the sub-Saharan El Niño rains cause floods and destruction,

while in the recent years droughts have also had catastrophic impacts. Consequently, harvest failure and incidents of food insecurity have become regular events occurring at least once or twice every decade and have been identified as a consisting of a convergence of social and political as well as natural factors (Eriksen et al. 2005).

Adger and Brooks (2003, p. 21) have interpreted the human ability to respond to climate change as involving 'socially determined futures over which there is a degree of space for action'. Determining the degree to which systems are sensitive and capable of adapting is the topic of a growing literature on both national and international agendas, though finding good indicators for the capacity to adapt to climate change has proved difficult (Vincent 2007). Singling out the driving forces and causalities that link vulnerability, poverty and climate variability remains a complex matter, and development policies aiming to reduce vulnerability to climate change variability still seem to be quite similar to traditional economic development policies. For example, studies aiming to identify measures that reduce rural households' vulnerability to climate variability often recommend drought preparedness, affordable grain, locally adapted seed varieties, improvement of access to markets for production inputs, promotion of investment incentives, weather forecasts and access to micro credit (Mortimore 2006; Roncoli et al 2001; Lacy et al. 2006)

The recognition of the exposure of systems to multiple stresses implies that development frameworks will need to consider the links between sustainable development and climate change. Additionally, this will involve climate change being brought into development planning, which will be critical in acquiring an understanding of what policies will work where and when. For this purpose, estimates of the costs and benefits of various adaptation options are necessary.

Research has shown that there will be little discrepancy between the impacts due to climate variability and climate change. Therefore, studies of present-day vulnerabilities to climate variability contribute to improving the understanding of the

impact of long-term climate change and of measures to facilitate adaptation (Smit et al. 2000; Kelly and Adger 2000). This is especially important, as adaptation has become a focus of policy through the UN Framework Convention on Climate Change. In addition, identifying and implementing adaptation measures to reduce vulnerability to current and future climate variability contributes to reducing vulnerability to future changes in climate.

1.2 Objective and research questions

This thesis aims to explore the consequences of climate change impacts for development in the context of the increasing attention and recognition being given to the former. In particular, the thesis focuses on the local variability of climate impacts on rural households, on how the resilience of households to climate change impacts can be strengthened, and the costs associated with adaptation to climate change impacts, mainly on the national levels. To this end, it examines whether it is economically beneficial to integrate climate change adaptation into development planning and whether the costs of inaction exceed the costs of adaptation. This synopsis serves to outline the rationale for this research area, and to explain the background to each of the research questions identified in the context of addressing the overarching aims of this thesis. The three main research questions are as follows:

1. How are rural households affected by climate variability?
2. How can rural households' resilience to climate change impacts be strengthened?
3. What are the costs associated with adaptation to climate change impacts?

Table 1 summarizes the research questions and related sub-questions.

The thesis aims to determine the consequences of climate change impacts on populations in developing countries. It aims to discuss measures and associated costs to reduce the consequences of these impacts with the objective of strengthening the

resilience of vulnerable populations to climate change impacts. As a result, the primary audience at which this thesis is directed consists of researchers and development planners as well as national policy makers. This work is positioned within specific conceptual and theoretical discussions, illustrated by case examples based on data from East Africa, primarily Tanzania.

Research questions	Sub-questions	Papers
How are rural households affected by climate variability?	What is the consequence of climate variability to rural households?	Paper 1
	How do households respond to variability in known weather patterns?	
How can rural households' resilience to climate change impacts be strengthened?	How can adaptive capacity be strengthened by financial and other instruments?	Paper 1 and Paper 2
What are the costs associated with adaptation to climate change impacts?	How can adaptation be supported by general development planning?	Paper 4
	What are the costs to society of climate change impacts?	Paper 3
	What are the costs of adaptation measures?	Paper 4 and Paper 3

The findings of the research are presented in the following four papers:

Paper 1: 'Local Patterns of Rainfall Variability and Household Coping Strategies in Northern Tanzania', accepted for publication in *Regional Environmental Change* in 2010.

Paper 2: 'Informal Networks and Resilience to Climate Change Impacts: A Collective Approach to Index-Insurance'. Submitted.

Paper 3: ‘The Health Impacts of Climate Change: A Study of Cholera in Tanzania’,
BC3 Working Paper Series 2010-01. Available at:
<http://EconPapers.repec.org/RePEc:bcc:wpaper:2010-01>.

Paper 4: ‘Development and Climate Change: A Mainstreaming Approach for
Assessing Economic, Social, and Environmental Impacts of Adaptation
Measures’, *Environmental Management* 43(5): 765–778 (2009).

2. Conceptual Framework

This chapter starts out by examining a core entry point for the research in this thesis, namely sustainable development. It then examines three related concepts within adaptation studies: vulnerability, resilience and coping. The concepts are commonly referred to within adaptation studies and also in this thesis, thereby increasing the importance of examining them more closely. Attention is drawn to their interconnectedness and links with adaptation. Lastly, adaptation and its related aspects are examined. Adaptation is closely related to the concepts of vulnerability and resilience and overlaps to a great extent with the concept of coping.

2.1 Sustainable development

Sustainable development is a broad concept that encompasses a range of issues related to economic, ecological and social/human dimensions. There exist several hundred definitions of the concept, and an early definition by Pearce, Barbier and Markandya (1990) suggested that sustainable development should imply that no generation in the future will be worse off than the present generation. Implicitly, society should not allow decreases in welfare over time.

Historically, the links between climate change and sustainable development have often been defined primarily as lying between mitigation and development. Nonetheless, climate change adaptation is now often associated with sustainable development in the literature (see e.g. AFDB et al. 2003; Munasinghe and Swart 2005; Klein et al. 2007), meaning that sustainable development presents a natural entry point for the work in this thesis, as it is in most adaptation studies. A number of studies highlight the benefits of adopting more sustainable practices leading to increased economic efficiency in the longer term (Johnson and Walck 2004; Epstein and Roy 2003). It is also increasingly acknowledged that development paths and

adaptive capacity are intrinsically linked (Yohe et al. 2007). This becomes true when economic development is achieved in the sense of sustainability, and economic development is regarded as an adaptation in itself. And second, as Smit argues (1993), adaptation is a practical means of achieving sustainable development.

As will be illustrated in the following section, therefore, the development path is an important contributor to the degree of a system's vulnerability. As Yohe et al. note (2007), vulnerability to climate change impacts will be most severe when they are experienced together with other stresses. These stresses include components of sustainable development such as access to resources, poverty, and food security.

2.2 Vulnerability

Within the economic literature, two main approaches to household vulnerability are proposed. In the first approach, vulnerability is defined as a decrease in consumption which can be attributed to an 'uninsured exposure to risks' (Hoddinott and Quisumbing 2003) or, more generally, to the lack of effective coping mechanisms. The second approach looks at the decline in living standards below a certain threshold, such as the poverty line. In both approaches, vulnerability reflects a downward trend in living standards. However, the second approach looks exclusively at those households whose decline is such that the poverty line is crossed. This definition of vulnerability excludes those households among the non-poor that are well enough off so that, when they experience a decline in welfare provoked by a shock, they remain non-poor. It also excludes those households that are already below the poverty line. This consideration is important since a decade of research on climate change vulnerability shows that inevitably it is the poor who are the most vulnerable and suffer the most from changing environmental conditions (e.g. Downing 2003; Adger et al. 2001; Smit and Pilifosova 2001; Ribot et al. 1996). Therefore, it is important to include other than solely monetary measures in the assessment of vulnerability to climate change impacts, even though the poverty rate remain a key

parameter to understand households ability to cope with and adapt to stress and disturbances.

In the context of climate change, the concept of vulnerability has gained increasing popularity in climate change studies in recent decades (Cutter 1996; Canon 1994, 2000; Wisner et al. 2004, Ribot 1996). Vulnerability is applied as a key concept in assessing who will experience the greatest impacts of climate change. Sen's entitlement approach (1981) is often cited as having built the foundations for examining causality in a systematic way and for laying the groundwork for vulnerability analysis (Kelly and Adger 2000; Adger 1996; Ribot 1996). The entitlement approach examines vulnerability in relation to people's access to different basic services that generate inequitable degrees of vulnerability. These measures include access to health care, food, education and land, as well as freedom of expression.

There are many attempts to define vulnerability in relation to climate change. The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as 'the propensity of human and ecological systems to suffer harm and their ability to respond to stresses imposed as a result of climate change effects' (Adger et al. 2007, p. 720). The vulnerability of a society is influenced by its development path, physical exposures, distribution of resources and institutional setting (Kelly and Adger 2000; Smit and Wandel 2006; O'Brien et al. 2004; Turner et al. 2003). It indicates that a system or simply people can be vulnerable to varying degrees, pointing to the root causes of equity and the entitlement approach. Vulnerability in this sense constitutes the conditions that increase the chances of damage following a particular trend or event. Associated with the definition of vulnerability, there is an implicit 'to', which remains important in answering the question, 'vulnerable to what?' (Green 2003; Suarez and Ribot 2003). Hence, a system-specific vulnerability refers to the vulnerability of particular systems or population groups to particular trends or events.

A common denominator for definitions of vulnerability is that the key parameters of vulnerability are the stress to which a system is exposed, its sensitivity, and its adaptive capacity (Adger 2006). The definition of vulnerability in this thesis is in line with these parameters. The exposure and sensitivity of households in a region in Northern Tanzania is explored in **Paper 1** in this thesis. The paper is framed to enhance the understanding of the role of local specificities in shaping the sensitivity of households to climate variability. Research to enhance the understanding of how sensitivity and exposure to climate variability affect households, and of how households deal with uncertainty and variability, is vital. Such efforts will contribute to the pertinent challenge of identifying the conditions that increase the risk of being vulnerable to particular trends in weather patterns. Identification of rainfall trends and events that trigger households to report negative effects on income help to identify the climate parameters that impact on rural households' livelihood activities. Considering these parameters together with the response strategies that households are using to cope with these disturbances will contribute to our understanding of the specific adaptive dynamics and options for vulnerable groups like rural households to ensure more effective targeting of policies and programs.

The exposure component of vulnerability is well illustrated in **Paper 3** and **Paper 4**. In **Paper 3** different exposure scenarios based on climate change variables and health data are constructed to analyze the exposure of cholera attributable to climate change. In **Paper 4**, the impacts of existing climate variability and predicted change are linked to several development indicators. In both papers analyses of exposure to climate change impacts are necessary to estimate the cost implications of such disturbances to general development objectives.

The differential impacts of disturbances due to different levels of vulnerability are well illustrated by considering the loss of lives and disruption to livelihoods after a flood in Mozambique compared with the impacts in the United States following a hurricane with resulting flooding. The overall financial cost of the impacts may be higher in the United States, but because of greater security networks such as

insurance schemes, people affected by the flooding will recover relatively quickly. In Mozambique, however, the financial cost of the impacts may be low, but for individuals and households the relative costs will be higher. People in developing countries are rarely insured against events affecting whole communities, and they will most likely experience difficulties in rebuilding their homes or refunding their lost assets. Negative health impacts from a flooding event will also be greater in a setting with poor sanitation infrastructure and a limited capacity in respect of health care systems. The provision and uptake of rural insurance schemes in developing countries remain limited (Dercon et al. 2008; Churchill 2006; Leftley and Mapfumo 2006) and **Paper 2** discuss and proposes an approach to insurance against crop failures caused by larger weather anomalies. The approach builds on the social attributes arising from informal networks, which, it has been argued, play a fundamental role in building adaptive capacity (Pelling and High 2005).

Vulnerability in the context of development provides a useful link between climate and development policy, and development failures may be reconsidered in the context of vulnerability to climate change. The costs of adapting and integrating climate change measures in general development policies and interventions to reduce vulnerability to climate change impacts are illustrated in **Paper 3** and **Paper 4**. The results shows that the negative impacts of climate change can be reduced for relatively small costs in comparison to the consequences of not integrating climate change impacts in development planning.

2.3 Resilience

Resilience is a term that is widely used in a range of scientific disciplines, but it has its origins in ecology, and more particularly the dynamics of ecosystems. The concept generally refers either to the extent to which a system may absorb the effects of a stress or shock, or to the recovery time after such a disturbance. The interest in resilience is reinforced by the increasing recognition that natural and social systems

behave in a non-linear way and interact as coupled, integrated systems (Folke et al. 2002). Rural communities and their economic activities are highly dependent on natural systems for their livelihoods, and social development is therefore related to nature in strong, dynamic ways. Natural resource systems are influenced by human actions, and a (mis-)use of resources can result in a shift to less productive or degraded states of natural resources, which may have negative consequences for the welfare of current and future populations. Such a shift reflects a loss of resilience as a result of increases in uncertainty for human livelihoods, vulnerability, security and conflicts.

In ecological resilience, resilience is conceptualized as the capacity to absorb shocks while continuing to function (Adger 2000; Peterson 2000). When change occurs, resilience provides the components for renewal and reorganization (Gunderson and Holling 2002; Berkes et al. 2002). Resilience is closely linked with the concept of vulnerability. As described in the previous section, the vulnerability of a system to climate change involves consideration of three aspects: the exposure, the sensitivity, and the resilience of the system owing to adaptive capacity. This implies that the less resilient the system, the lower the capacity of institutions and societies to adapt to and shape change (Perrings et al. 1995, Peterson et al. 1998, Chapin et al. 2000, Loreau et al. 2001, Diaz and Cabido 2001). When a system improves its resilience, its vulnerability decreases. When it loses resilience it becomes more vulnerable. The narrative stems from ecology, where the loss of a functional component or group in an ecosystem will severely affect the capacity of the system to reorganize after a disturbance. Walker et al. (2009) stress that biophysical, social, and economic factors are treated as components of one single system delivering goods and services to humans. Nonetheless, it may be problematic to assume that the behaviors of social and ecological systems are practically identical. The behavior of and change in social systems can be much more rapid and unpredictable than in an ecological system.

The resilience is related to both the number of participants within a functional group and the overlapping functioning between groups. Similarities can be drawn between

this mechanism to increase resilience and the social capital framework discussed in **Paper 2** in this thesis. The social capital framework uses the term ‘bonding’ to describe relations within groups, and ‘bridging’ to illustrate associations with other groups. In **Paper 2** it is argued that the characteristics of social capital approaches can be used to increase the resilience of rural households to community-wide shocks.

Often, resilience is also used to describe the desirable outcome of adaptation processes. In the climate change literature it is often used to describe a system characteristic that determines how the impacts of climate change will be experienced. Resilience is therefore closely linked with the concept of adaptive capacity and vulnerability to climate change. Reenberg (2009) notes that using resilience rhetoric can have a more practical purpose as a way of characterizing aspects of sustainability, adaptive capacity, and the performance of human-environmental systems. In some literature (Smit et al. 1999; Carpenter et al., 2001; Trostler 2002) resilience has been equated with returning or bouncing back to the original state of a system before disturbance. However, with this approach resilient systems do not necessarily develop once they have recovered their original state and make the concept of resilience distinct from adaptation if adaptation is viewed as a process rather than an outcome.

2.4 Coping

Households have coped with climate trends and shocks for decades (Mortimore and Adams, 2001; Mertz et al., 2009), and some rural households in dryland areas have even moved away from climate dependency in their livelihood strategies (Nielsen and Reenberg, 2010, Reenberg 2009). This provides evidence that, despite being vulnerable to climate change impacts, households and communities are not helpless victims. The term coping is sometimes used as a synonym for adaptation (Fankhauser, 1998), but coping measures are usually regarded as short-term responses to avert immediate threats (Berry 1989; Ellis 1998; Huq and Reid 2004;

Vogel 1998), in opposition to adaptation, which requires adjustments in practices to continuous or permanent changes.

The literature and research on coping has mainly addressed food security, particularly in the context of drought and seasonality. Searching through the literature, it seems that there is some conceptual confusion attached to coping. One dominant approach is to treat coping as a response to an abnormal season, event or year (Davies 1993). In line with this, Adger describes coping strategies as ‘short-term adjustments and adaptations to extreme events, [which] are usually involuntary and almost invariably lead to a different subsequent state of vulnerability’ (Adger 2000, p. 357). This use of the concept associates an inability to cope with high vulnerability and low resilience. The second approach addresses coping as a strategy which may not necessarily involve an abnormal situation which needs responding to. Here, coping represents a normal component in the lives of subsistence farmers in developing countries, and coping strategies are viewed as seasonal adjustments. People who live in a fluctuating environment will change their behavior and strategies as a response to the variable environmental conditions they depend on. In this approach, coping is regarded as responses to disturbances which are part of the norm. Adopting such an approach would make it difficult to distinguish between situations in which households or communities are coping with extraordinary situations and situations in which the responses are normal behavior, which would not be considered a coping strategy in the first approach.

In order to identify responses related to climate change impacts, coping must be considered in the context of extraordinary situations or extreme events that are the consequences of climate change. If coping strategies are integrated into a household’s livelihood strategy, the household must be assumed not to be adapted to the conditions it is confronting. That said, it should be kept in mind that coping strategies are relative. Selling chickens in the market may be one household’s livelihood strategy, while for another household it may be a coping strategy caused by harvest failure, forcing the household to sell off its productive assets. In addition, it has been

argued that coping strategies vary between time, space and scale according to preferences, objectives, opportunities and barriers. **Paper 1** in this thesis emphasizes the local differences in coping strategies that households follow. The lessons learned from different coping strategies, and the types and extent to which specific coping strategies are relied on in particular communities, may lead to an increased understanding of the capacity for responding to different types of short-term impacts and the respective consequences for welfare and development. However, coping strategies are generally resorted to in order to overcome a situation and do not imply adjustments to new conditions. The concept of coping is therefore distinguished from that of adaptation.

In situations in which change appears to be more long term and extreme events occur more frequently, coping options will often prove inefficient or will potentially cause harm. Some strategies can be harmful to the natural environment in terms of resource depletion, soil erosion or other problems. This can have a negative influence on household welfare in the longer run in the form of decreases in income and available food crops. A commonly used coping strategy among households in developing countries is support from informal networks (Townsend 1994; Grimard 1997; Lyon 2000; Roncoli et al. 2001; Ligon et al. 2002). These networks may nonetheless prove insufficient in periods of climate change, when extreme events or simply negative trends affect whole societies more frequently. For example, a drought which affects the majority of a risk-sharing network will make the network fail as a fall-back position for risk-sharing in such a situation. **Paper 2** in this thesis deals with this issue and discusses how the capacity of informal networks can be improved to deal with the implications of climate change impacts.

2.5 Framing adaptation to climate change

Adaptation to climate change essentially involves describing the adjustments made to changed environmental conditions. The changes take place naturally within biological systems and to some extent in social systems (Gallopín 2006; Nelson et al. 2007).

The concept of adaptation is not new and is broadly used about the adaptations of living organisms to changed situations. The use of the term ‘adaptation’ in a scientific context originates in the literature on evolutionary biology and Darwin’s concept of natural selection (Smit 1993). It has entered the larger interdisciplinary field of global environmental change, changing more in the direction of a concept used by researchers and others to guide policymaking with the aim of securing sustainable and equitable development in the light of a changing climate. In particular, promoting adaptations for places and livelihoods that are sensitive to climate change impacts is critical. Throughout history, human societies have adapted to a changing climate, but it is considered that future climate change will increase the need for adaptation (Parry et al. 2007). Nonetheless, to identify good adaptation practices, it is important to build on existing knowledge and the adaptations already taking place. Good adaptation practices in this sense should be understood as measures which reduce vulnerability to climate change by means of increased resilience to negative impacts while at the same time promoting other goals of sustainable development.

The perception of adaptation within the climate change literature is generally ‘adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities’ (IPCC 2001, p. 982). Importantly, this definition includes both climate variability and climate change. It is this definition of adaptation by the IPCC that has been adopted by the papers in this thesis.

There exist a broad range of different adaptation typologies, presented in a number of concepts and frameworks. One such interpretation is that adaptation is also considered as a measure with which to embrace and take advantage of new circumstances and conditions presented by changes. For example, Osbahr et al. (2010, p. 2) note that, ‘adaptation is the adjustment of a system to moderate the effects of climate change to take advantage of new opportunities’.

Some concepts that are directly related to adaptation are discussed in the following sections. Adaptive capacity and maladaptation are directly related to adaptation. Mainstreaming adaptation into general development planning has received increasing attention in recent years, and inevitably estimates of the costs and benefits of adaptation measures are used in discussing such efforts.

2.5.1 Adaptive capacity

Adaptive capacity was conceptualized by Folke et al. (2002) as the ability to cope with novel situations without losing future options. The IPCC notes that ‘the capacity to adapt is dynamic and influenced by economic and natural resources, informal networks, entitlements, institutions and governance, human resources, and technology’ (Adger et al. 2007, p. 719). With this passage, the IPCC introduces the features of adaptive capacity into the sphere of general development objectives. Adaptive capacity is most commonly assumed to depend on a number of resources which constitute the asset base that lays the foundation for initiating adaptation. Vincent (2007, p. 13) defines adaptive capacity as ‘a vector of resources and assets that represent the asset base from which adaptation action can be made’. The main factors constituting adaptive capacity focus mainly on indicators such as economic wealth, technology, information and human capital, infrastructure, institutions and equity. But also other indicators, including life expectancy, insurance mechanisms, access to public health facilities, and other general development outcomes, have been included in analyses (Klein 2001).

In developing countries there is often inadequate infrastructure, a lack of well-functioning institutions, little access to technology, large inequalities and high poverty levels. These conditions generally give developing countries a low capacity to adapt to climate change. The concept of adaptive capacity therefore seems inversely correlated with that of vulnerability, where the conceptual link between adaptation and vulnerability is constituted by adaptive capacity. On these grounds, a system with high adaptive capacity could be adapting to changes and possess low vulnerability to the impacts from climate change. Assessing indicators of both vulnerability and adaptive capacity are perceived by many as helpful in identifying vulnerable systems and their ability to respond to stresses (Downing et al. 2001; Yohe and Tol 2002; Adger et al. 2004). Nonetheless, adaptive capacity represents the potential for the system to adapt, and a high level of adaptive capacity only reduces a system's vulnerability to future impacts from climate change. Adaptive capacity enables the system to adapt to longer term changes over a more or less long period, but it does not provide resilience against immediate impacts such as flooding.

Recently, research on adaptive capacity has brought social issues into the discussion. Several authors, including Osbahr et al. (2010), Pelling and High (2005), Adger (2003) and Adger et al. (2007), have argued that the role of institutions and social capital is substantial in the facilitation of effective adaptation. Osbahr et al. (2010) examine the social elements of what they define as successful adaptation. One of these elements is related to the concept of adaptive capacity and the mechanisms for social learning. Social learning constitutes an important contributor to knowledge transfers between individuals, and most importantly between key individuals and the wider community. By reinforcing and strengthening informal networks, as well as links between actors from different scales, including those participating in the networks, interaction and communication at village level have been shown to increase adaptive capacity. Strengthening networks or institutions facilitates collective action, thus enabling individuals to transcend the limitations of acting alone. Such possibilities are explored in **Paper 2**, which argues that a collective approach to

insurance will increase the uptake and efficiency of insurance and strengthen the capacity of communities and households to adapt to climate change.

Due to its characteristics, adaptive capacity is not only unequal across developing and developed countries, but also within and across societies. Most of the literature on adaptive capacity recognizes that analyses of adaptive capacity are most useful if they are carried out on differentiated scales and not only by looking at one level. Exploring national, regional and local contexts for adaptive capacity will provide policy makers with information on both the constraints and opportunities that social systems are facing in their efforts to cope with and adapt to changing conditions. The literature that **Paper 1** in this thesis builds upon even argues that policies need to target local specificities to be effective (Kristjanson et al. 2005; Okwi et al. 2007).

There seems to be a lack of consensus in the literature on both the usefulness of adaptive capacity indicators and the consistency of results (Brooks et al. 2005; Haddad 2005; Eriksen and Kelly 2007). There remain difficulties in how to assess adaptive capacity beyond existing development measures and in how the result should be applied. Building adaptive capacity also seems to be closely associated with building a general capacity for sustainable development outcomes. The concept and indicators of adaptive capacity nevertheless remain useful when it comes to understanding the components and prerequisites for adaptation.

2.5.2 Maladaptation

Adaptation measures may increase the vulnerability or even undermine the resilience of other systems, groups or individuals if the strategy imposes externalities at other spatial or temporal scales. Maladaptation is defined by the IPCC (2001, p. 990) as ‘an adaptation that does not succeed in reducing vulnerability, but increases it instead’. Water extraction upstream for irrigation in dry areas may impose negative externalities for downstream communities. In addition, maladaptation may not only

increase vulnerability but can also generate new risks. This is evident in a situation in which an adaptation measure has high opportunity costs expressed by high economic, social or environmental costs relative to alternative adaptation measures. Nelson et al. (2007) note that a system's resilience, together with its adaptability, is part of a path dependency trajectory of change in which present decisions affect future management flexibility. Reducing exposure to current climate variability can therefore adversely affect vulnerability to future climate change impacts. It is the consequences of poorly planned and targeted policies that can result in negative consequences for all, or only for some groups. In this context, it is important to note that it is not only policies which are specifically related to climate change issues that may have adverse impacts, but also policies in other areas, for example, the industrial sector, trade and globalization. One example is the increased use of air-conditioning in response to heat waves and its consequential health impacts (Kovats et al. 2006). The maladaptation occurs in the sense that using air-conditioning is energy demanding and will increase emissions of greenhouse gases. This will increase the need for further adaptation in the future.

Failing to integrate adaptation into development planning and policies can result in maladaptation, where initiatives enhance rather than reduce vulnerability to the impacts of climate change.

2.5.3 Mainstreaming adaptation into development planning

Mainstreaming climate change adaptation into development planning and policies has increasingly emerged as a policy strategy that recognizes the links between development and climate change adaptation. The concept of mainstreaming has previously been used in development policies, where the issues of gender and HIV are most commonly associated with mainstreaming. Mainstreaming climate change promotes a shift in the responsibility for implementing strategies from individual

ministries and agencies dealing with climate change issues to all sectors of government, agencies and also civil society.

The aim of mainstreaming climate change is to ensure that current as well as future strategies are well adapted to the climate. USAID (2009, p. 49) defined the mainstreaming of climate change as ‘the integration of climate concerns and adaptation responses into relevant policies, plans, programs, and projects at the national, sub-national and local scales’. As described in **Paper 4**, the idea is basically ‘to assess climate change and its impacts and vulnerabilities in the context of development’.

To begin with the mainstreaming initiative was primarily donor-driven, since many developing countries previously did not consider climatic change to be one of their greatest concerns. During the last five to ten years, a range of mainstreaming efforts have emerged from the donor community. The approaches range from mainstreaming guidance documents to targeted tools and methodologies. The guidance documents aim to conceptualize a framework for mainstreaming at various levels rather than detailed, operational instruments on how to implement mainstreaming in practice. Danish Development Assistance (Danida) was one of the first international donor agencies to initiate the integration of climate change in its assistance (Danida 2005). Another example is the recent activity by the OECD (2009), which has outlined a conceptual framework for addressing mainstreaming at all levels. The tools and methodologies used, such as the World Bank’s ADAPT tool (World Bank 2010b), are intended to support specific components of mainstreaming, including at different levels. Gigli and Agrawala (2007) and Olhoff and Schaer (2010) have summarized the various donor efforts in climate change mainstreaming.

The benefits of mainstreaming climate change into development planning are illustrated in **Paper 4**. Mainstreaming appears to have the advantage of making more efficient and effective use of financial and human resources, rather than designing, implementing and managing climate policy separately from other ongoing activities.

By providing an approach to climate change mainstreaming, **Paper 4** aims to contribute to the understanding of the mainstreaming of climate change adaptation into development planning and its associated benefits.

2.5.4 Assessing the costs and benefits of adaptation

The total economic burden of climate change is related to three major areas: the costs of mitigation, the costs of adaptation, and the costs of residual impacts that can neither be mitigated nor adapted to. Estimating the costs and benefits of adaptation to climate change is important for the discussion regarding the levels and choice of investments needed for adaptation. Intuitively, the costs of adaptation refer to the costs a system or society spends on adapting to changing conditions. Following the IPCC (2001), adaptation costs are the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transaction costs. The World Bank (2010a) defines adaptation costs as additional to the costs of development. Consequently, the costs of measures that would have been undertaken even in the absence of climate change are not included in adaptation costs, while the costs of doing more, doing different things, and doing things differently are included. The measure of adaptation benefits refers to the fraction of climate damages that are avoided by specific adaptation actions (Callaway 2004).

In order to operationalize the economic estimate of an adaptation measure, the analysis is divided into several elements. As a first step, it is necessary to compare the specific situation with and without climate change. A projected situation with economic development but without climate change is called the baseline. This is compared with a situation which includes economic development and climate change projections. In this way it is possible to compare the two situations, for example, by 2050 and to estimate the residual impacts and their costs created by climate change. The residual impacts are the difference between the two scenarios. Such an analysis is, for example, undertaken in **Paper 3**, where scenarios for 2030 are established in

order to estimate the health impacts from climate change and related costs in Tanzania.

A number of organizations have made attempts to calculate the total costs of adaptation in developing countries. The most recent assessment by the World Bank (2010a) estimates adaptation costs at US\$ 70-100 billion a year between 2010 and 2050. Oxfam (2007) estimated annual costs at close to US\$ 50 billion per year, while the UNDP suggests that adaptation costs may amount to US\$ 86-109 billion per year (Watkins 2007). The UNFCCC (2007) estimated the additional investment and financial flows needed worldwide to be \$60–182 billion in 2030, some \$28–67 billion of which would be needed in developing countries. The above cost estimates are widely used to demonstrate the need to increase the funds available for adaptation in developing countries. The evidence provided by these studies emphasizes that the longer it takes to limit greenhouse gas emissions, the higher the damage and human suffering will be, and consequently the costs of adaptation.

The literature on the costs and benefits of specific adaptation measures on the national and local levels remain relatively scarce but are increasingly being studied as part of broader planning exercises to develop national strategies. This is evident at both the country and sector levels. It is to this literature that **Paper 3** and **Paper 4** add to existing knowledge. The papers estimate the costs and benefits of investments in several adaptation measures, on both a national and a more local level. A recent series of case studies initiated by the World Bank (2010a) elaborates on the costs of adaptation in developing countries. These studies support the conclusion that although adaptation is relatively costly, the impacts of climate change without adaptation will be much more costly.

2.5.5 The limitation of uncertainty

The estimate of the costs and benefits of adaptation is complicated by several uncertainties. These uncertainties are associated with the lack of a consensus in projections of climate change, and with incomplete information on the path of economic growth and technological change (World Bank 2010a). For many countries there is no consensus on whether climate change will result in wetter or dryer conditions, or how great the changes will be in the frequency and magnitude of major storms. For example, **Paper 4** uses climate change projections for Mozambique and Tanzania. Here predicted changes in precipitation for Tanzania include an increase of 5–30 percent during rainy seasons for some parts of the country. For Mozambique, projections indicate that climate change may lead to significant changes in water runoff, which will consequently increase the frequency and magnitude of flooding, though the magnitude is not certain. Therefore, decisions about investments in assets with a life-time of 20, 30 or maybe 40 years, including drainage, water storage, bridges and other infrastructure, will have to be based upon incomplete information, given the large degree of variation in climate change projections. Similarly, **Paper 3** uses predictions of economic development. Predicting economic growth is also connected with some uncertainty. Faster economic growth will put more assets at risk and possibly increase the potential risk of damage, but as a result of higher levels of investment and technical change, it will also result in higher levels of flexibility and of the capacity to adapt to climate change. Also, predictions of innovation and technological development seem complicated and difficult to account for. Therefore the cost calculations in **Paper 3** and **Paper 4** do not allow for these unknowable effects on technologies.

Assumptions made about these uncertainties are widely adopted in a range of adaptation cost studies (for example, World Bank 2010a; Parry et al. 2009) and in general analyses of economic sectors with extended time horizons. The uncertainties further stress the importance of implementing development activities that reduce the

underlying vulnerabilities of a system in general, and of enhancing the adaptive capacity as a strategy for integrating climate change adaptation into development.

3. Paper Summaries

The papers presented in this thesis are in the form in which they have been published (Papers 3 and 4), accepted for publication (Paper 1), or in line with the style in this introduction (Paper 2). Henceforth, they are adjusted to the format requirements of the respective journals and working paper style. The published and accepted papers have been peer reviewed. The journals include a multidisciplinary journal (Paper 4), a regional journal (Paper 1), and a working paper series within economics (Paper 3).

Paper 1 analyses local patterns of rainfall in the Kagera region of northern Tanzania and household self-reported shocks to income because of harvest failure. It also examines the responses of these households concerning how they cope with these shocks. The paper sets the scene for assessing why it is important to analyze the implications of climate change on resource-constrained populations in developing countries. It emphasizes the importance of taking into account the local conditions that shape adaptation.

The conclusions drawn in **Paper 1** feed well into the justification for the next paper, **Paper 2**. This paper concentrates on risk-sharing through informal networks, which is one of the central strategies that many households draw on to cope with shocks. The problem with using informal networks as a coping strategy arises when the majority of a community is hit by the same shock. In such a situation, the informal networks may cease to function as a safety net. As an alternative, participation in formal insurance schemes has the potential to increase households' resilience to climate variability. Nonetheless, there is limited success with the provision and uptake of rural insurance schemes in developing countries. **Paper 2** introduces an approach to overcoming the remaining barriers to the uptake of formal insurance schemes, and the approach offers a way to utilize the benefits of social capital arising from informal networks. The proposed insurance scheme is a collective form of index-insurance, that is, insurance linked to a measurable indicator such as rainfall. The collective

approach suggests that targeting households through existing semi-formal and informal networks will bring several benefits, increasing households' trust in the insurance provider, as well as making the schemes more economically efficient for insurance providers. This approach is applied to a case study from Tanzania based on the same data as the analysis in **Paper 1**. The example indicates that there exists a potential for applying such an approach to index-insurance in the area of the case study.

The next paper, **Paper 3**, moves from the more local to the national level to analyze the economic consequences of climate change impacts. The focus in this paper is on the health impacts of climate change, namely cholera, in Tanzania. To allow for an estimate of adaptation costs, the paper establishes the relationship between the incidence of cholera and environmental and socioeconomic factors. On this basis, it is possible to estimate the number of additional cholera cases and deaths which can be attributed to climate change by 2030 in Tanzania. This study is the first study which links cholera with both environmental and socioeconomic data and which uses this relationship to estimate climate change impacts on the prevalence of the disease in the future. The results presented in **Paper 3** support the conclusion that climate change will increase the financial and human burdens on societies as well as households. It further emphasizes that there are considerable benefits to be drawn from preventive measures in comparison to the cost of reactive adaptation measures in the form of treatment of the disease.

The costs and benefits of adaptation measures are also covered in the last paper in the thesis, **Paper 4**, which focuses on how adaptation measures can be integrated or mainstreamed into general development planning. The paper offers a pragmatic approach to addressing climate change vulnerabilities and adaptation as a mainstreaming issue. The paper makes use of three case studies where a simple set of indicators is used to provide representatives of crucial development policy objectives to illustrate the application of the mainstreaming approach. In line with the results of Paper 3, **Paper 4** illustrates the economic feasibility of reducing climate risks.

An important point throughout these papers is that vulnerability to current and expected climate variability must be reduced, and that the vulnerabilities to a number of impacts in the different sectors are influenced by many factors, none of which can be addressed in isolation.

Besides the papers included in this thesis, I have co-authored the following papers during my work for my PhD:

Christensen, J., and S. Trærup (2009), ‘Adaptation to Climate Change in Least Developed Countries – Challenges, Experiences, and Ways Forward’. *The Science and Technology Review* 4.

Abstract:

Climate change represents a profound challenge to the lives and livelihoods of everyone, but in particular to those living in developing economies who are acutely dependent on natural and nature-based resources. This short paper emphasizes that, as part of a new global climate deal in Copenhagen, it will be essential to ensure that adequate and predictable international funding is made available to support developing countries and especially LDCs in their aspiration to develop more climate-resilient societies.

Trærup, S., and N. Veje Laursen (2009), ‘Ensuring Sustainable Development within a Changing Climate’. Paper presented at the International Human Dimensions Programme on Global Environmental Change (IHDP) Open Meeting 2009, ‘Social Challenges of Global Change’, Bonn, Germany, April 27–30.

Abstract:

In 2000, the international community agreed on the Millennium Development Goals, which aim to reduce poverty by 50 percent by 2015, as well as to improve on other social and development indicators. For many countries the MDGs are quite ambitious

and require intensive efforts in order to be achieved by 2015. To halve poverty through economic growth implies a sustainable development path that takes into account the possible adverse impacts of climate change.

This paper builds on the experiences of a climate-change Action Programme and illustrates how national development plans can prove vulnerable to adverse climate change impacts. It is suggested that climate-change considerations can be strengthened in national planning to minimize vulnerabilities and simultaneously enhance adaptive capacity at the national level in order to contribute to sustainable economic growth and development. Vulnerable sectors and major vulnerabilities are identified against the background of natural disaster data and projected climate-change impacts. The sustainability of respective national planning efforts in the light of climate change will be assessed by a review of selected national development plans and strategies. Thereafter, examples are given of how to strengthen ongoing efforts in integrating climate considerations into existing national development plans.

The countries in focus are Bangladesh, Bolivia and Mozambique. The intention with this selection is to include different aspects of climate change impacts and adaptation options – there is no ‘one size fits all’ though a lot of similarities across countries do exist.

4. Conclusion

The research in this thesis focuses on the impacts of and adaptation to present variations in climate and to projected future changes. The research has dealt with different levels, i.e. household/community, national/policymaking, and sectoral level, to show different perspectives of the implications of climate variability and change to development. In particular, it focuses on how present variations in rainfall patterns affect rural households, ways to strengthen households' resilience to climate variability, and the costs and benefits of adaptation measures. The research attempts to contribute to the knowledge that informs the development community and national governments for policy-making on the implications of climate change on development planning and strategies. It is argued in the thesis that it is essential for sustainable development to mainstream climate change into strategies and planning where relevant. To do this a knowledge of the costs and benefits of diverse adaptation measures is essential.

Fluctuations in annual and seasonal rainfall, both in terms of modest and excessive rains, are found to cause negative shocks to rural household incomes in the Kagera a region of Tanzania. An analysis of rainfall and household data for the region shows large local discrepancies in the distribution of rainfall, as well as in households reporting shocks to income caused by harvest failure. It is also evident from the research results that the timing of rainfall seems to play a greater role than the level of annual precipitation. The coping strategies that households report following subsequent to a harvest failure further show local divergence in the choice of, for example, taking casual employment and relying on support from others in the form of informal networks. These results support earlier work which points in the same direction and emphasizes that policies should be targeted to local specificities. This provides a great motivation for targeted responses to climate change instead of exclusive national strategies.

Building on existing coping strategies in efforts to support adaptation may contribute to overcoming prevailing barriers to some adaptation initiatives. The resilience of rural households to changes in climate could be fortified by a strengthening of the existing informal networks as risk-sharing institutions. An agricultural insurance provided through existing informal networks has the potential to strengthen the resilience of the networks and their members to community-wide shocks. Surely, one such initiative is only one measure among many, in light of the fact that adaptation is closely interlinked with central development issues.

This thesis has demonstrated that there is a large potential for integrating climate change adaptation into already existing and on-going development programmes, projects and planning efforts, and that this can be done for relatively low costs. It is vital to quantify the burden of impacts attributable to climate change at the national and local levels, as opposed to exclusively at the regional level, to enable informed national and local decision-making. Accordingly, improved projections of future climate and related risks are necessary. Nevertheless remaining uncertainties should not prevent or postpone adaptation. For example, the scenarios for the health burden (as shown specifically for cholera) attributable to climate change in Tanzania are already of sufficient concern to justify building adaptation responses into planning. This is a good reason for accelerating planned sanitation and drinking water programmes, where, of course, the measures themselves will have to be adapted to, for example, increased salinity in inland water systems caused by changes in climate.

Above all, this thesis shows that it is necessary, feasible and economically efficient to integrate adaptation measures into planning efforts in order to ensure long term sustainable development within a changing climate.

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Paper 1



‘Local Patterns of Rainfall Variability and Household Coping Strategies in Northern Tanzania’, accepted for publication in *Regional Environmental Change* in 2010

Rainfall variability and household coping strategies in northern Tanzania: a motivation for district-level strategies

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Abstract

Climate variability is an important stress factor for rural livelihoods in most developing countries where households have been adapting to environmental shocks for decades. Climate change results in increased variability and poses new challenges for rural livelihoods, as well as for policy-makers in adjusting policies to changing conditions. This paper examines the potential relationships between rainfall data and household self-reported harvest shocks and local (spatial) variability of harvest shocks and coping strategies based on a survey of 2700 rural households in the Kagera region of northern Tanzania. The results show that rainfall patterns in the region are very location-specific and that the distribution of household reported harvest shocks differs significantly between districts and correspond to the observed variability in local climate patterns. Coping strategies are focused on spreading risks and include reduced consumption, casual employment, new crops, external support and the selling of assets. There are no large differences in applied coping strategies across the region, but district-level data demonstrate how local strategies differ between localities within the districts. The results emphasize that in order to target rural policies and make them efficient, it is important to take into account the local conditions that rural households face when experiencing climate-related shocks. Finally, shocks reported by households appear to correspond well with observed variability in rainfall patterns.

Keywords: climate variability, self-reported harvest shocks, coping strategies, local distribution, Tanzania

1. Introduction

Climate change today is resulting in increased climate variability (IPCC 2007). The impacts of increased climate variability are pronounced, especially in Least Developed Countries (LDCs), where most agricultural production systems are rain-fed and where people have few resources to cope with and adapt to these changes. Climate variability and droughts are already important stress factors in Africa, where rural households have been adapting to such shocks for decades (Mortimore and Adams 2001; Mertz et al. 2009a), and in very dry regions they have even moved 'beyond climate' dependence in their adaptation and coping strategies (Nielsen and Reenberg 2010). Nonetheless, rural households are likely to experience greater uncertainty in their rural production, and the negative shocks and trends from increased climate variability will affect rural livelihoods, thus exposing rural household welfare to greater levels of risk (Cooper et al. 2008; Paxson 1993; Udry 1994; Alderman 1996; Lim and Townsend 1998; Deaton 1991; Alderman and Paxson 1994; Fafchamps and Lund 2003; Kazianga and Udry 2006). Consumption smoothing is also more difficult with repeated shocks than with a single shock (Alderman et al. 2006). Repeated over longer periods, existing coping strategies can degenerate the asset base and even amplify households' vulnerability to climate change impacts. Consequently, household welfare is most likely to be depreciated.

The climate change debate has stimulated an increasing interest in measuring and analyzing human vulnerability (Eakin and Luers 2006; Vincent 2007; Mertz et al. 2009a). Vulnerability to climate change impacts is the degree to which a system is susceptible and unable to cope with the adverse effects of climate change (IPCC 2007; Adger 2006). The key parameters of vulnerability are the stress to which a system is exposed, its sensitivity and its adaptive capacity. Thus the vulnerability of a household will determine its ability to respond to and recover from the shocks.

When a large negative shock occurs, the usual household activities may not yield sufficient income. Studies have reported high income variability related to risks of various forms associated with fluctuations in crop yields (Townsend 1994; Kinsey et al. 1998). If all the households in a community, district or region are affected,

local income-earning activities are unlikely to be available or sufficient. In this case, relying on the support of family members or others may not be possible unless they have migrated and can contribute with remittances. In such a situation, formal or informal insurance transfers (credit or insurance) from outside the community are necessary, while inter-temporal transfers (e.g. the depletion of individual or community-level savings) are also possible. Besides seeking assistance, households may also pursue other activities as part of their coping strategies. Many examples, including temporary migration to find jobs, longer workdays, collecting wild foods and collecting forest products for sale are reported (e.g. Thornton et al. 2007; Davies 1996; De Waal 1987).

Keeping livestock as an asset to cope with shocks is another common strategy as a flexible and mobile resource with lower dependence on climate factors (Mertz et al. forthcoming), and it may solve short-term problems. The returns can also be negative, however, as a severe drought may cause destocking due to livestock death or low fertility (Dercon 2002). The consequence may be the loss of some or even all livestock just when it is needed as part of a self-insurance scheme.

The overall conclusion of these studies is that most households succeed in protecting their short-term consumption from the full effects of income shocks, but that in the long term these shocks have consequences for low-income households, which are forced to, for example, reduce their investment in children's health and schooling, or sell productive assets in order to maintain consumption. These consequences raise an argument for targeting policies to increase such vulnerable households' ability to resist and respond to these shocks. To target policies it is necessary to identify, and differ between, the conditions that make households vulnerable, besides being poor. Even though that difference in access to basic resources such as water, infrastructure and public facilities are recognized as major contributors to differences in household welfare, there exists little work to explore the degree of variation from one locality to another. While this type of work has been limited mainly by lack of adequate data and resources, studies by Kristjanson et al. (2005) and Okwi et al. (2007) suggest that policies need to target local specificities to be effective. Building on their work and

recognizing that vulnerability of a society to climate variability is influenced by its development path, the physical exposures, the distribution of resources and the institutional setting, this paper aims to explore local patterns of climate variability and potential impacts from this on local communities. The recognition of variation in local factors may feed into both local and national policy making aimed at reducing poverty and improving the ability to respond to climate variability and associated shocks.

For the examination of exposure to climate variability and influence on households' livelihoods, there is a growing literature that contrasts local perceptions and scientific records on climate data in Africa. Ovuka and Lindquist (2000) found that Kenyan farmer perceptions of decreasing trend in rainfall correspond with recorded monthly and annual rainfall data. This result is further verified by studies in South Africa (Thomas et al 2007) and Burkina Faso (West et al. 2008). Results from Senegal (Mertz et al. 2009b) also point in the direction of corroboration between actual and perceived evidence on rainfall. As a contrast to these studies, Meze-Hausken (2004) found no evidence of correlation between peoples perceptions and recorded rainfall data from Ethiopia. Building on this literature, this paper analyzes households' self-reported harvest shocks against recorded rainfall data.

Not only the amount but also the timing of rainfall is essential to ensure stable crop development and secure the efficiency of farm inputs (Antle et al. 2004; Porter and Semenov 2005). Rosenzweig et al. (2002) computed that, under scenarios of increasingly heavy precipitation, production losses due to excessive soil moisture have the potential to double by 2030. In scenarios with higher rainfall intensity, Nearing et al. (2004) projected increased risks of soil erosion. Cooper et al. (2008) simulated crop productivity in maize for an area in Kenya under increased climate variability with an increase in the total amount of rainfall. The results showed considerable yield variations, with contrasting patterns of seasonal rainfall distribution. Probabilistic projections for major crops based on multiple global circulation models, however, did not project significant crop losses in 2030 in East Africa with the exception of cowpea (Lobell et al. 2008).

Another study using a single climate model with a multiple scenario assessment shows yield increases for cassava, sorghum, rice and millet in East Africa and decreases in wheat and maize yields by 2030, the latter mainly in Tanzania (Liu et al. 2008). There are relatively high discrepancies in the results of these two studies, which demonstrate the difficulties involved in predicting future crop yields and the extent to which harvest shocks will become more frequent in the future. There is, however, agreement that variability in climate in general and rainfall in particular are important sources of production and price risks which can lead to income fluctuations for rural households. The focus has mainly been on inter-temporal changes within a given location or region and the local (spatial) variability of such climate factors has often been neglected.

Consequently, the objective of this paper is to examine to what extent rural households experience shocks to income arising from rainfall variability and to explore how rainfall patterns vary from one locality to another. In addition, the paper looks into the local patterns of how households cope after a shock and link the spatial distribution of coping strategies with environmental conditions. This will provide some basic background which could benefit policy-makers in targeting interventions with regard to rural extension services etc. The paper is organized as follows. Section 2 presents the local context of the research area. This includes an introduction of local conditions at district level. Section 3 introduces the applied data and methodology and section 4 analyses the results and provides a discussion of these. Finally, section 5 concludes.

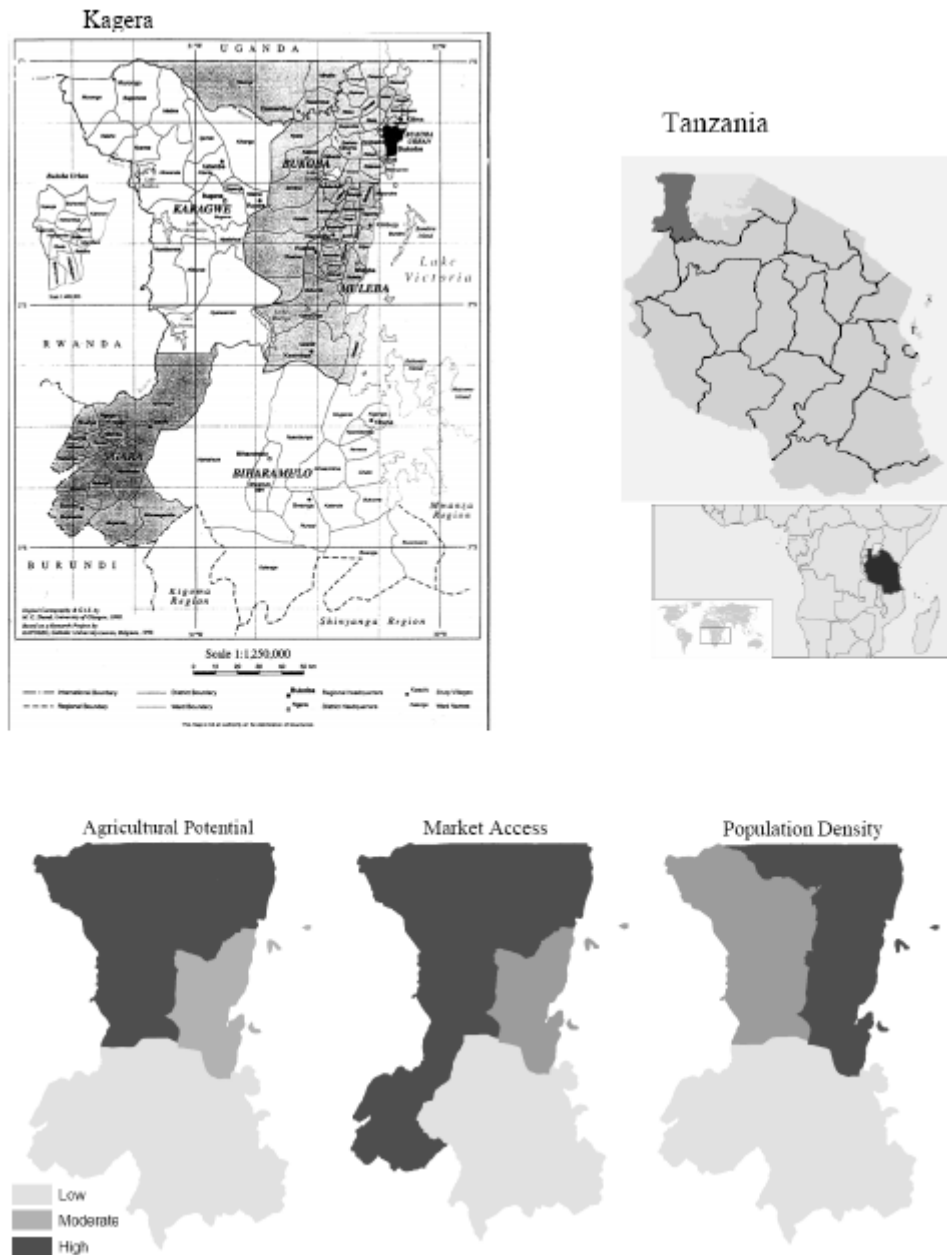
2. The local context

The Kagera region is the remotest region from the administrative center in Tanzania of Dar es Salaam situated in the northwestern part of Tanzania by the shores of Lake Victoria and borders Rwanda, Burundi and Uganda (Figure 1). The infrastructure in Kagera is characterized by poor roads compounding the isolation further. Kagera has a varied topography, with tropical vegetation, including forests and wide-open grasslands. Large parts of the region are characterized by

low soil fertility and – mainly in areas near and along the lake shores – soil erosion on sloping land is another problem (URT 2003). Nonetheless, the region produced between 1996/1995 and 2000/2001 an annual surplus of 681,000 tons of starch food (URT 2003). It is, however, the region in Tanzania with the lowest per capita GDP and 29 percent of all households in Kagera live below the basic needs poverty line (URT 2002b).

The rainfall pattern in Kagera is bimodal, with annual rainfall ranging from 1000 to 2000 mm. The rainy seasons are defined as March-April-May (long rainy season) and October-November-December (short rainy season). In the long rainy season, the data used in this paper shows that Kagera receives on average 41 percent of total annual rainfall, while the short rainy season receives on average 32 percent. The remaining 27 percent falls mainly in January and February. Table 1 presents a summary of the recorded rainfall data for Kagera as a total mean and for the respective districts. The data reveals large differences in variability in between the districts. Karagwe in the north experiences large variability from year to year, with a 1600 mm disparity, while Ngara in the south, on the contrary, receives significantly less average rainfall, but with less variability both within rain seasons and between years.

Figure 1: Districts in Kagera region and the distribution of population density, agricultural potential and market access



The population data are based on the Tanzania Population and Housing Census (National Census Bureau of Tanzania 2002) and depicts population density for 2002 by fourth-level administrative unit (wards). To estimate market accessibility, locations are classified according to distance to road, road quality and distance to nearest town. It is assumed that all areas are equally accessible outside roads, all transportation on roads is assumed to be by motor vehicle, and transportation outside roads is assumed to be walking. The analysis of market accessibility is based on data from Africover available at <http://www.africover.org>. Agricultural potential is based on average annual rainfall and soil quality. Rainfall data is available from the KHDS data set and soil quality is based on data from International Livestock research Institute (ILRI) available at <http://www.ilri.org>

The population of Kagera is approximately two million people (according to the 2002 Census), and the population density varies between the six districts of Biharamulo, Bukoba Rural, Bukoba Urban, Karagwe, Muleba and Ngara (Figure 1 and Table 2). Given that urban and rural households have different vulnerabilities and livelihood strategies, Bukoba Urban is excluded from the analysis in this paper where the focus is on rural areas.

Table 1. Recorded rainfall data in Kagera Region and districts from 1980 to 2003

	Bihara- mulo	Bukoba Rural	Karagwe	Muleba	Ngara	Kagera
Long season						
Mean rainfall	477	754	543	700	414	624
% total	38	42	39	43	41	41
Min rainfall	200	534	256	409	252	368
Max rainfall	975	1160	1038	1671	598	1106
Short season						
Mean rainfall	418	546	490	511	414	485
% total	34	30	35	31	41	32
Min rainfall	207	336	214	256	252	255
Max rainfall	724	777	1004	1023	598	862
Yearly						
Mean rainfall	1243	1799	1400	1637	1008	1508
Min rainfall	846	1109	795	1113	760	1024
Max rainfall	1390	2259	2338	3080	1387	2166

Source: own calculations based on Kagera Health and Development Survey (KHDS). The KHDS data and documents are available at <http://www.worldbank.org/lsmis/>

In some parts of Kagera, land ownership is customary. For example the land belongs to a clan and clan members approve any agreement related to selling of land. The livelihoods of the rural population are primarily based on a range of rain-fed annual crops such as maize, sorghum and tobacco in the south and bananas and coffee in the north. Mainly traditional cultivation methods and tools are used, and capital investments are minimal, with land and labor as the principal factors of production. These aspects render agricultural production in the region, and thus rural livelihoods, highly dependent on the agricultural potential of land resources, water availability, the availability of land and access to local markets. All these factors vary a great deal between the districts, with Ngara having the lowest degree of population density, agricultural potential and market access (Figure 1).

Table 2. Characteristics of rural Kagera.

	Bihara- mulo	Bukoba Rural	Karagwe	Muleba	Ngara	Rural Kagera
Population	410,794	395,130	425,476	386,328	334,939	1,952,667
Mean household size	5.8	4.7	4.7	4.3	4.6	4.7
Pop. density (person/km ²)	46	73	56	155	76	70
Literacy rate (%)	51	68	61	61	50	63
Cultivated area (ha.) per household	0.39	0.95*	2.22	0.67	0.99	1.06
Employment, agriculture (%)	80	84	84	86	90	75
Mean per capita annual expenditure (USD 2004)	110	175	181	166	141	155

Based on URT (2002a), and KHDS. * includes Bukoba Urban

Drawing on information from Kessy (2005), De Weerd 2008, and EDI (2004) the districts in rural Kagera are characterized by intra-district heterogeneity in livelihood vulnerabilities and opportunities. The slopes in the northern district, Karagwe, make transportation of agricultural products to the local markets burdensome, but roads leading into Uganda and market centers are relatively good. Therefore the population in Karagwe has the potential to benefit economically from its geographic location. It is also the most highly populated district together with Bukoba Rural. After agriculture, the major income generating activity in Karagwe is livestock keeping. Households in Bukoba Rural also gain from access to markets in Uganda and base their livelihoods mainly on banana and coffee growing. Because of the location next to Lake Victoria, households in Bukoba Rural have access to fishing, which is the second most important income generating activity in the district after agriculture. Likewise, households in Muleba districts also gain from fishing opportunities, as a supplement to agriculture, and have relatively good market access to the center in Bukoba Urban. At the same time population density is quite high and contributes to existence of local markets and trade.

Biharamulo is the poorest district in Kagera and is located in the southern part of the region. Soil quality is poor and rainfall is well below the Kagera average. As a contrast to households in the northern districts, who base their livelihoods to a large extent on banana/coffee farming systems, households in Biharamulo rely generally on sorghum/coffee/cotton farming systems. Tobacco production is increasing after a collapse of coffee and cotton markets. Ngara is, according to the KHDS data, the second poorest district in the region and it is the least populated district. It has little rainfall and low soil quality. These factors render agricultural production difficult in Ngara, but the district has the advantage of relatively good market access, not least to markets in Rwanda and Burundi. A livelihood system based on banana and coffee farming together with fishing activities enable households to sustain income and food security even during years with large anomalies in weather patterns. In districts where households mainly rely on agriculture for income and food intake, households would be expected to be more vulnerable to sudden or unexpected shocks to income and crops. Such heterogeneities surely exist not only between districts but also between households within each district.

In Tanzania, there are a number of key institutional structures and policy instruments in place at municipal level, including municipal land-use planning integrating perspectives on exposure to natural hazards, risk and emergency plans, and climate and energy plans. The proposed projects under the National Adaptation Programme of Action (NAPA) in Tanzania is planned to be implemented with high level ministries, such as Ministry of Agriculture and Food Security, but in cooperation with Local Government authority, Tanzania Meteorology Authority, local communities, and NGOs. This may provide a basis for an increase in capacity at local scales in order to cope with climate change as well as it could increase formal responsibilities for land-use and other planning. Local level vulnerability assessments could in this way be a key instrument for municipalities and may pave the way for integrating climate change perspectives in local governance. However, at this stage the NAPA assessment of vulnerabilities and adaptation strategies focus on country level factors and

therefore may miss out on local complexity and lead to too generalized conclusions.

3. Data and methodology

The analyses of household shocks and coping strategies are based on household survey data from the Kagera Health and Development Survey (KHDS) 2004. The KHDS data and documents are available at <http://www.worldbank.org/lsms/>. The KHDS was originally adapted from the World Bank's Living Standards Measurement Study (LSMS) questionnaires and consisted of 912 households interviewed in three waves from 1991 to 1994, in nearly 50 communities. The 2004 wave used in this paper consists of over 2,700 households from the baseline of 912 which were re-contacted because people had moved out of their original household. One of the main purposes of the KHDS was originally to collect data that can be used to analyze the impact of HIV/AIDS, which has been a major problem in Kagera, with prevalence rates of 24 percent during the 1980s (Beegle et al. 2006). One concern which arises using this data set is that the survey design originally included an over-sampling of households considered to be at risk based on the following criteria: those with a sick adult and/or those households that had experienced an adult death in the past two years at the time the first household was listed (about six months before the first survey round). It is possible that households that have experienced a death in earlier years respond differently to shocks. However, the 2004 wave used in the analysis of this paper was collected thirteen years after the first wave, and therefore the household may have overcome the difficulties caused by a death or illness. Nonetheless, this must be acknowledged as a limitation of the analysis.

A second concern is that the analysis uses the section of the KHDS based on households' perceptions of shocks to income due to weather-related harvest failures. Using self-reported shocks may contain some weaknesses, as self-reported shocks are by definition subjective and dependent on the perceptions of the individual included in the sample. This implies that one individual might report an occurrence of harvest failure, while another household in the same

community, or even in the same household, might perceive the situation differently and thus not report any occurrence of harvest failure. The question on self-reported shocks in the KHDS questionnaire asks what type the respective years were. It is therefore not possible to draw conclusions regarding the length of the hardship. And even though five opportunities for answers were provided regarding whether they had a good or bad year, the affirmative answers may still cover heterogeneous responses (Tesliuc and Lindert 2004). For example, some households in the same area may have lost most of their harvest and thereby a large potential income share due to heavy rains during or after the harvest season because they had only limited storage capacity. On the other hand, other households in the same area could also have reported the shock, but did not experience as large a negative impact to income and experienced less loss than the other households as they were able to store their harvest properly, away from the rains. These types of differences in responses cannot be extracted from the survey and will be a weakness that must be acknowledged in the analysis.

The analysis in this paper was mainly carried out at district level, this being justified by the differences in rainfall patterns within the region and because rural households rely heavily on agricultural production, which is closely linked to rainfall quantity and distribution. The KHDS data refers to administrative districts before 2000 (after which Bukoba Rural and Biharamulo were subdivided).

Monthly rainfall data was obtained from the KHDS. The data covers the period from 1980 to 2004 collected from a total of 21 rainfall stations distributed between the districts in the region. The stations are spatially distributed with 2 stations in Biharamulo, 7 in Bukoba Rural, 5 in Karagwe, 4 in Muleba and 2 in Ngara. Comparison with longer time-series of rainfall and reports from FAO indicates well coherence with the KHDS rainfall data. The year 2004 lacks a number of observations from Biharamulo, Ngara and Muleba. In addition, Biharamulo lacks three observations from 1999 and one each from 1993, 1997 and 2000. Bukoba Rural lacks one observation each from 2001 and 2004. Based on this, year 2004 was removed from the analysis, while the remaining missing observations were accounted for during the analyses by omitting these months for the respective districts. Temperature is also important for agricultural production,

but mainly for long-term changes in agricultural potential (Lobell et al. 2008; Liu et al. 2008). Therefore, temperature is omitted in this paper, the focus being on short-term shocks.

4. Results and Discussion

4.1 Rainfall variability and shocks to household income

The shocks that households in Kagera have reported are primarily related to death, harvest failure and illness (Table 3). This paper is limited to examining shocks defined as low income due to poor harvests of agricultural crops caused by unfavorable weather conditions, since these can be expected to be linked more or less directly to climate variability. This type of shock will hereafter be referred to as a harvest shock.

Table 3. Distribution of shocks reported by households in Kagera 1994-2003.

	Bihara- mulo	Bukoba Rural	Karagwe	Muleba	Ngara	Rural Kagera	N
Death in family	20	48	26	34	24	31	275
Low harvest, weather	28	14	33	15	40	22	230
Serious illness	37	14	16	14	16	18	157
Loss of assets	4	3	4	9	5	6	51
Low crop prices	2	3	6	6	1	5	48
Wage employment lost	2	3	2	8	1	5	30
Other	7	14	13	12	13	13	111
N	50	385	140	181	146		902

Source: own calculation based on KHDS 2004. The numbers are presented in percentage of total number of shocks within each district.

Shocks related to death, illness, low crop prices and lost wage employment can also be linked to climate variability, but the links are less direct and difficult to examine. Examples include increases in the incidence of malaria, which are major contributors to illness and deaths and have been attributed to increased climate variability in several studies (WHO 2003; Zhou et al. 2004; Wandiga et al. 2006; Abeko et al. 2003). Crop prices and employment opportunities are, among other things, influenced by agricultural productivity. Prices are affected by supply (crop yields and market access), while demands for labor are affected by seasonal fluctuations.

Overall, the distribution of harvest shocks in Kagera (Table 4) during the ten-year recall period gives the impression that 2000 and 2003 were the years with the least favorable weather conditions for producing crops. The years 2000 and 2003 dominate, with almost fifty percent of the total number of recorded harvest shocks.

Table 4: District harvest shock distribution.

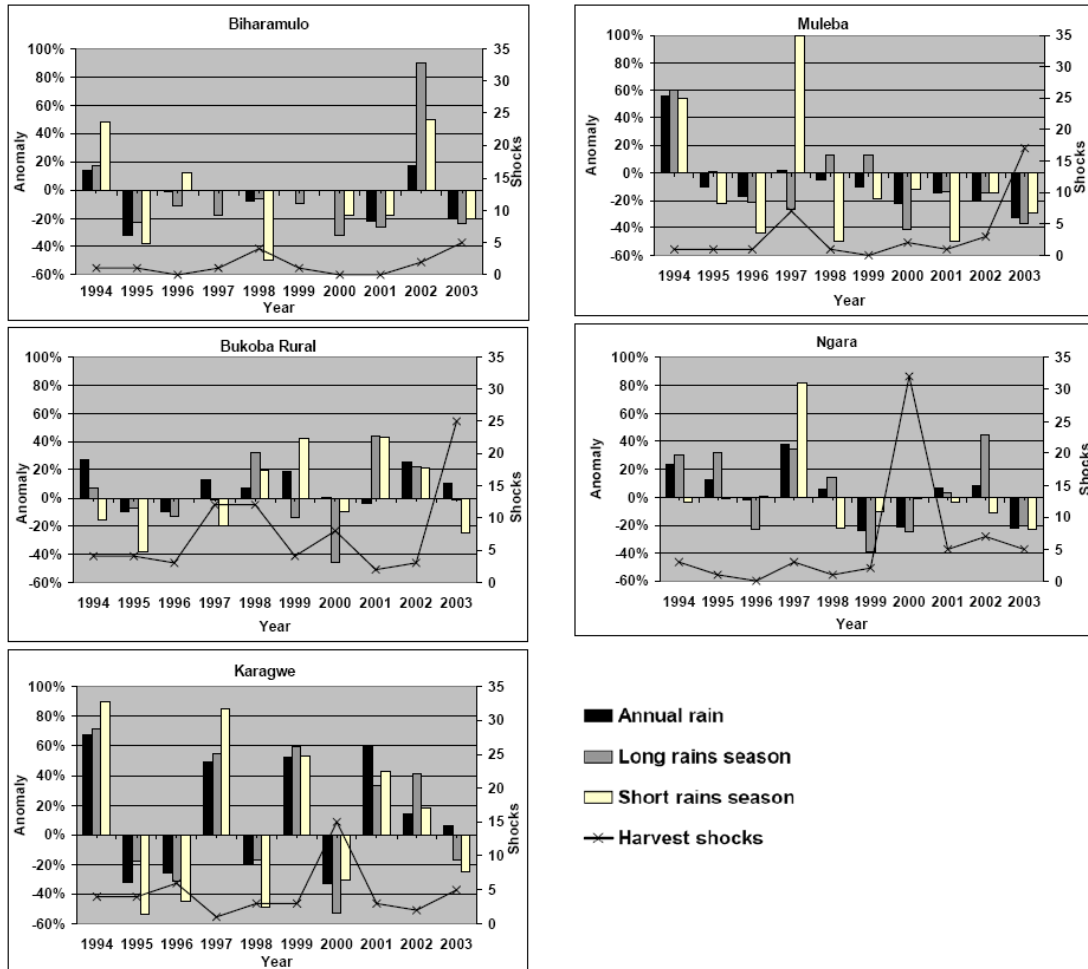
	Biharamul o	Bukoba rural	Karagwe	Muleba	Ngara	Rural Kagera	
1994	1	4	4	1	3	13	
1995	1	4	4	1	1	11	
1996	0	3	6	1	0	10	
1997	1	12	1	7	3	24	
1998	4	12	3	1	1	21	
1999	1	4	3	0	2	9	
2000	0	8	15	2	32	57	
2001	0	2	3	1	5	11	
2002	2	3	2	3	7	17	
2003	5	25	5	17	5	57	
Total	15	77	46	34	59	230	

The numbers represents actual number of households reporting very bad income shocks caused by harvest failure. Source: own calculations based on KHDS

The district-level analysis shows a different tendency, and the frequency of shocks is unevenly distributed between the districts. It appears that the distribution of reported harvest shocks is very much district-specific, with considerable variations between both years and districts (Table 4). Three districts in particular, Bukoba Rural, Karagwe and Ngara, have high frequencies of reported harvest shocks. There may be a wide number of reasons for this, such as farm mismanagement, pest attacks, or even illnesses and deaths in the family. Nonetheless, if Table 4 is compared with Figure 2, it appears that the distribution of households reporting shocks seems to be associated with variability in rainfall. Figure 2 shows rainfall anomalies on an annual and seasonal basis. The Figure also reflects the distribution of shocks presented in Table 4. Assuming that there is a correlation between the frequency of households reporting harvest shocks and rainfall patterns, harvest shocks seem to be associated with variability in terms of excessive rains in a season, dry spells and cumulated patterns, the latter meaning that excessive rains in one year can result in households reporting harvest shocks in the forthcoming year.

The rainfall data show large disparities in rainfall patterns between the districts. Overall, households reporting harvest-related income shocks are over-represented in districts with relatively large annual and seasonal variability: Karagwe, Bukoba Rural, Ngara and Muleba. In the district with relatively stable rainfall patterns, Biharamulo, the frequency of households reporting shocks is low. The trends in rainfall patterns based on the data from 1980 to 2004 point towards a shift in onset of rainfall and general patterns. With the exception of Biharamulo, where rainfall has remained almost stable, all districts have experienced an increase in amount of rainfall. The period outside the rainy seasons from June to September remains relatively dry, while, except for Biharamulo, the January-February rainfall trend shows a large increase especially in January rainfall. Especially Bukoba Rural has an increasing trend in amount of rainfall for the two rainy seasons as well as the January-February rains.

Figure 2. Rainfall anomalies calculated based on deviation from the medium-term district mean rainfall records (1980-2003) received in any given year



The lines are associated with the secondary x-axis and show the frequency of households for each district who reported harvest shocks in respective years. Source: own calculations based on KHDS.

Unfortunately, the number of observations with regard to households reporting shocks is too limited to allow a statistical analysis of the relationship between shocks and rainfall patterns.

One conclusion, which can be drawn from this, is that large local differences exist between the districts. Rainfall variability and shock distribution both vary, and aggregated data for Kagera does not provide valuable information at the regional level for policy-makers.

4.2 Household coping strategies

Over time, rural households develop a range of coping strategies as a buffer against uncertainties in their rural production induced by annual variations in rainfall combined with socio-economic drivers of change (Cooper et al. 2008). These coping strategies spread risk and aim to reduce the negative impacts on household welfare from income shocks due to harvest failures. Coping strategies may be preventive strategies such as altering planting dates, introducing other crops and making investments of water equipment, or may be in-season adjustments in the form of management responses. Lastly, they may be reactive strategies used after the negative impacts or the so-called shock due to harvest failure. The latter most often include consumption smoothing, the sale of assets such as livestock, remittances from family members outside the household and income from casual employment (Niimi et al. 2009; Kinsey et al. 1998; Kochar 1995; Dessalegn and Rahmato 1991; De Waal 1987). It has also been argued that coping strategies for small rural households vary both between households and over time according to preferences, objectives, and the capacity to change. The capacity to change includes financial and technological issues as well as the willingness to change traditional thinking.

Based on qualitative data, Kessy (2005) identified a number of strategies among households in rural Kagera for coping with a sudden or anticipated shock. Among the most important strategies were depletion of assets, namely selling livestock, especially goats and agricultural produce. Also mortgaging land was mentioned as a coping strategy, whereas selling land is very rare, partly due to the local land tenure as described in section 2. The majority of households in Kagera do not have many assets to deplete and depend on their land to counter shocks. For example a respondent in Kessy (2005) experienced a severe storm that destroyed all his banana plants. As a coping strategy he planted short term crops such as sweet potatoes, and beans to take them through while waiting for the bananas to mature. Consequently, the dependency of land makes mortgaging of land problematic and may push the household further down the poverty ladder. Lack of

assets further contributes to the vulnerability of poor households since it is not possible to borrow money without collateral.

For an expected shock or when the households have a longer period to react, cattle is sold a priori in the nearby cattle market where the seller gets a better price compared to selling to a rich man in the village. In such a situation access to markets is of great importance. When given more time to react households would seek employment, make local brew or borrow money from relatives and friends. However, in case of a community wide shock households would borrow money or seek remittances from households in nearby villages. The importance of remittances from children residing elsewhere has increased the interest among households in Kagera to invest in children’s schooling as an insurance for parents’ old age. The majority of households also referred to “do nothing” in case of a community wide shock. Only a few households were found to accumulate savings. Banks are absent, and keeping too much cash in the household is perceived as dangerous because of the risks of theft and fire. Lastly, assistance from government or non-governmental organizations was mentioned as inevitable during community wide shocks. Lundberg et al. (2005) found evidence that the poorer households in Kagera mainly rely on private remittance relative to the better off households who have better access to more formal credit institutions. Such evidence highlights the importance of improving access to formalized credit due to the risk of hardship not only affecting one village but several neighboring villages which face the same climate conditions.

Table 5: Households’ main coping strategies for harvest shocks in rural Kagera 1994-2003.

Coping strategy	Bihara- mulo	Bukoba Rural	Karagwe	Muleba	Ngara	Rural Kagera	N
Reduced consumption	33	40	37	24	69	44	102
Casual employment	47	35	30	41	37	36	84
Intro. of other crops	33	19	11	32	20	21	48
Support from others	13	21	22	18	14	18	42
Sale of assets	13	16	17	12	19	16	37
N	27	122	84	60	104		397

Source: own calculation based on KHDS. The table gives percentages of total number of households in each district reporting a harvest-related shock.

In the KHDS questionnaire, households were asked how they coped after a harvest shock. The responses are shown in Table 5 and correspond well with the

strategies identified in Kessy (2005). In four of the six districts, reduced consumption is the most important coping strategy. Reduced consumption is most likely associated with the strategy of “do nothing” as mentioned by Kessy (2005). In the two remaining districts, Biharamulo and Muleba, casual employment is the most important strategy. In the four districts where reduced consumption is the most important strategy, casual employment is the second most reported strategy. Support from others, or remittances, shows up as an important coping strategy in most districts. The introduction of alternative crops also plays an important role and must be considered a preventive strategy, one that assumes unfavorable production conditions for the next season. Looking into the data, again there are large disparities between the districts. Karagwe and Bukoba Rural, which are the main producers of banana and coffee, have the lowest percentages of households reporting the introduction of new crops as a coping strategy. In these districts fifty percent of nutrition intake comes from bananas (Gallez et al. 2004), while coffee production is a major cash crop contributing substantially to rural incomes (URT, 2003). Households in Kagera that produce bananas and coffee are less likely to diversify their farming activities and more prone to fall into poverty (DeWeerd 2008). In the southern districts, where production mainly relies on annual rain-fed crops such as maize, sorghum and tobacco, which are easier to substitute than coffee and banana, there seems to be a tendency for households to be more likely to introduce new crops as a response to harvest failure.

The available data do not permit us to identify the new crop varieties which are being introduced. However, evidence from the literature suggests that uncertainty of rainfall patterns generally causes households to behave differently from how they would have done if the weather was known (Phillips et al. 2000; Mendelsohn et al. 2007). This uncertainty generally leads households to choose crops that will resist larger weather extremes and are tolerant of weather variations, but most often their yields are lower, and farmers invest in a lower level of inputs than the optimal, due to the risk of losing the investment. Lack of communication of seasonal forecasts and inadequate extension services in Kagera further contribute to inefficient agricultural practices. Kessy (2005) notes that despite the presence of agricultural extension officers, information on good crop husbandry are

generally not extended to a majority of farmers. Previous efforts from Africa have shown that access to climate information can be effective and contribute to reduce vulnerability of rural livelihoods to climate variability (Patt and Gwata 2002; Patt and Winkler 2007; Ziervogel 2004). Communication of seasonal forecasts should be addressed in any regional or district policy guidance, especially with a view towards mid-season review. An extension officer can also draw attention to the role of the following year's soil and crop management subsequent to an abnormally wet or dry year.

As a consequence of the different household responses between districts, the need to target policies to the local conditions that households are facing is emphasized. In areas where households are likely to introduce new crops, improved information on future seasonal patterns and supervision of suitable crops with expected seasonal rainfall patterns could turn out to be beneficial. In areas where households are less likely to introduce other crops, policies on the management of current crops could prove valuable. In both situations shorter-term seasonal weather forecasting would reduce the uncertainty of weather patterns and hence the risk of less beneficial decision making. It has been demonstrated that farmers in both East and West Africa see opportunities to benefit from seasonal weather forecasts (Rao and Okwach 2005; Roncoli et al. 2009;).

5. Conclusions

The analysis of reported harvest shocks and rainfall data indicated coherence between the number of shocks and anomalies in rainfall patterns with relatively large annual and seasonal variability both in terms of modest and excessive rains. Furthermore, the results of the analysis of harvest shocks showed large discrepancies between districts in the distribution of shocks. The rainfall data further revealed large local divergences in rainfall patterns, with dissimilarities in both magnitude and seasonal or annual variability between districts. Districts with more rainfall and large seasonal variability experienced more shocks than districts with less rainfall and less seasonal variability. The conclusion of this analysis is that the timing of rainfall appears to affect the distribution of harvest shocks more than the magnitude of annual precipitation. However, this could not be

statistically proven due to data limitations. A change in timing of rainfall would nonetheless encourage mid-season planning strategies to take advantage of the increasing trend in rainfall outside regular rainfall seasons. A change in timing of rainfall together with extreme rainfall events, including both drought and excessive rains, also emphasize the increasing need for multi-year planning.

The local differences between the districts are further emphasized in the analysis of coping strategies that households follow in response to harvest shocks. While the results for the region as a whole do not reveal great differences in applied strategies, district-level data demonstrates how local strategies differ between localities.

Breaking out of a low productivity–low income trap, which can be intensified by increased climate variability and inadequate coping strategies, requires a locally targeted approach to enable households to access fully and benefit from policies such as promoting improved technology, efficient markets and supportive strategies. The returns on policies and development initiatives in one locality will depend upon the respective challenges and conditions that households and institutions confront. For example, initiatives on rainfall harvesting for irrigation in crop production during dry seasons can be expected to result in a much higher return if the intervention is fitted to approximate local rainfall distribution.

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Paper 2



‘Informal Networks and Resilience to Climate Change Impacts: A Collective Approach to Index-Insurance’. Submitted.

Informal Networks and Resilience to Climate Change Impacts: A Collective Approach to Index-Insurance

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Abstract

This article contributes to the understanding of how to proceed with the development of index-insurance in order to reach extended population coverage with the insurance. The approach is applied to an example from a region in Tanzania. One of the main coping strategies that resource-poor households rely on to manage risks related to fluctuations in income flows is risk-sharing in informal networks. An informal network is an ideal way of managing idiosyncratic shocks, but once such shocks become covariate and affect whole communities, as is the case with most climate change impacts, informal networks become insufficient since the majority of risk-sharers will be affected by the shock at the same time. This paper proposes a collective approach to index-insurance in which the members of an informal network will be insured as one insurance taker. The paper raises a conceptual argument that targeting households through existing informal networks will remove a number of prevailing barriers to the take-up of insurance and consequently the approach has the potential to increase households' resilience to climate change impacts. The policy implications of the conclusions are significant since the number of covariate shocks is predicted to increase with climate change.

Keywords: climate change; resilience; informal networks; index-insurance

1. Introduction

In developing countries, resource-poor households generally depend on natural resources for their livelihoods. Weather factors therefore contribute to uncertainties and associated risks in the livelihood production outcomes of these households. Informal networks play an important role in enabling households to cope with these uncertainties and risks (Townsend, 1994; Grimard, 1997; Lyon, 2000; Roncoli et al., 2001; Ligon et al., 2002). Through risk-sharing among the members of an informal network, the members strengthen their resilience to extraordinary or unexpected costs related to events such as family births or deaths, sickness, weddings or harvest failure. Nonetheless, in spite of the fact that informal networks have the ability to help households cope with idiosyncratic shocks such as deaths or sickness, they provide insufficient protection against covariate shocks. A covariate shock affects the majority of a community, meaning that risk-sharing networks within communities can easily break down when almost all members are affected by the shock (Ray, 1998; Linnerooth-Bayer et al., 2005). Idiosyncratic shocks are by definition not correlated and therefore can be mutually insured within a network. If an event such as harvest failure is caused by weather anomalies, it will most likely affect the majority of the members of an informal network, given that they live within the same geographical area. In such a situation the role of informal networks as a fall-back position is weakened, and the network's members will be less resilient to weather-related shocks. Climate change creates a new situation with increasing variability of known weather patterns and unpredictable rainfall (IPCC, 2007). The frequency of situations in which weather anomalies weaken informal networks thus increases with climate change.

The uncertainties and risks associated with factors such as rainfall and temperatures challenge the resilience of rural households. In this context, resilience is understood as the capacity to absorb shocks while still maintaining function. Kasperson and Kasperson (2001) argue that, when a natural resource dependent community loses

resilience, the community increases its vulnerability to shocks which could previously have been absorbed. The less resilient a community, the lower is its capacity to cope with, adapt to or shape change. Thus the resilience of communities enhances the likelihood of sustaining development in changing environments where the future is unpredictable and where surprise is likely (Levin et al., 1998; Holling, 2001). Communities which have strong risk-sharing social or informal networks have proved to be more resilient to shocks since risks can be transferred across members and time (Moser, 1996; Narayan, 1997). Such informal networks typically include women's groups, burial groups, religious groups and cooperative farming groups.

The information, trust and norms of reciprocity that arise from such informal networks have been characterized as social capital (Woolcock, 1998). Social capital theories have been applied widely in public health policy (see Mladovsky and Mossialos (2008) or Moore et al. (2006) for a review), and recent empirical studies have suggested that high levels of social capital are positively correlated with progress with agriculture, water and sanitation, as well as with microcredit in developing countries (Anderson et al., 2002; Brown and Ashman, 1996; Krishna, 2001; Lyon, 2000; Narayan and Pritchett, 1997; Uphoff and Wijayarathna, 2000; van Bastelaer and Leathers, 2006). The importance of social capital in building private and public institutions of resource management to increase resilience to climate change is demonstrated in Adger (2003). This is in agreement with Pelling and High (2005), who argue that social attributes play a fundamental role in building adaptive capacity to climate change. Another example is Brondizio et al., (2009) who point to the central role of social capital in facilitating cross-level environmental management of natural resources.

Because of the increasing number of covariate shocks and the inability of informal networks to cope with them, new initiatives are required in order to improve resource-poor households' resilience to the new situation being caused by climate change. One such initiative which has received growing interest within development communities is index-insurance schemes (see, for example, Osgood and Warren

2007; Patt et al., 2010; Helmuth et al., 2009; Barnett and Mahul 2007; Meze-Hausken et al., 2009). Index-insurance is a form of insurance that has been introduced in recent years mainly as pilot projects in a number of countries (Giné and Yang, 2009). The index-insurance is designed to hold out promise for poor rural households. Nonetheless, a number of studies have identified a general lack of trust and poor understanding of insurance schemes as remaining barriers to poor households taking out insurance (Churchill, 2006; Cohen and Sebstad, 2006; Dercon et al., 2006, Leftley and Mapfumo, 2006). This lack of understanding has been found to correlate with a low willingness to purchase insurance (Patt et al., 2010). The literature on providing agricultural insurance to poor households in developing countries has focused on issues related to the willingness to pay, financial risks and economic barriers to taking out insurance. However, the literature has not solved the issues of how to overcome barriers related to trust and confidence in the insurance product among insurance takers.

The microfinance literature shows that the use of existing social ties improves access to credit for poor households (see, for example, van Bastelaar, 2000; Grootaert and van Bastelaar, 2002; Okten and Osili 2004) and has demonstrated the importance of informal networks in providing credit access to poor households. The networks have shown an ability to close gaps in the financial structure that commercial banks and institutions are unwilling or unable to fill.

The aim of this paper is to raise a conceptual argument concerning how to overcome trust-related barriers between insurance providers and insurance takers to taking out index-insurance. The paper further argues that the combination of social capital arising from informal networks and the opportunity to transfer risk out of the network to a wider geographical area through formal insurance schemes will increase the resilience of networks and their members to covariate shocks. The policy implications of the conclusions are significant since the number of covariate shocks is predicted to increase with climate change. The present paper therefore contributes to the

understanding of how to proceed with the development of index-insurance in order to reach extended population coverage with it.

The structure of the rest of the paper is as follows. Section 2 discusses experiences acquired from developments within the literature on rural insurance and informal networks respectively. This is followed by an argument for a collective approach to index-insurance. Section 3 provides a case example from Kagera region, Tanzania, and analyses the potential for applying a collective approach to index insurance in this area. Finally, Section 4 concludes the paper.

2. The conceptual approach

In developing countries, formal insurance schemes have primarily been used to avoid economic losses associated with health risks (Allegrì et al., 2009): only limited attention has been given to weather-related agricultural risks (Morduch, 2006; Meze-Hausken et al., 2009). This lack of focus on rural insurance may be due to the number of problems which are associated with this type of insurance (Alderman and Haque, 2007). First, an insurance provider does not have access to the same information as the insurance taker in circumstances when potential insurance takers know more about their own risks than the insurance provider does. This may lead to adverse selection where a majority of insurance buyers have a higher than average risk. In a situation of adverse selection, the overall costs of providing insurance will increase and make the provision of insurance less economically feasible for insurance providers. It may also lead to an increase in the price of premiums and thus make it less attractive for insurance takers to purchase insurance. A second problem with rural insurance is related to the moral hazards which occur in a situation in which rural households change their behavior or reactions as a result of having insurance. Moral hazard may occur in a situation in which a rural household chooses not to use the optimal input level of fertilizer in order to save on input costs. Assuming that crop

yields are dependent on a number of variables besides water and temperature, such as fertilizer, soil fertility and labor input, crop yields will decline with lower levels of inputs than the optimal level. As a consequence of low crop yields caused by low fertilizer input, the household will apply for compensation from the insurance provider even when rainfall has been adequate. In addition to problems of moral hazard and adverse selection, traditional crop insurance experiences problems related to high transaction costs, which are themselves associated with the monitoring of actual crop yields and administrative costs. These problems are not limited to the insurance sector in developing economies but are equally valid in developed economies.

The following parts of this section discuss the pros and cons of index-insurance, followed by a discussion of the role of social capital in risk-sharing networks. These discussions argue for a collective approach to index-insurance. The argument builds on the idea that social capital acquired from informal networks can contribute significantly to reducing barriers related to a lack of trust and confidence in taking out index-insurance.

2.1 Index-insurance

The interest in index-insurance in developing countries has increased in recent years as an alternative to traditional crop insurance. Index-insurance is inexpensive and affordable for rural subsistence households with modest incomes. Index-insurance is a form of insurance linked to an easily measurable indicator such as rainfall, temperature, humidity or crop yields which provides the basis for an index. Traditional forms of insurance are typically linked to actual losses of the insured item. A more detailed analysis of the construction of a rainfall index-insurance scheme would go beyond the scope of this paper (see, for example, Alderman and Hague, 2007), but index-insurance reduces several of the problems related to

traditional crop insurance schemes, as described above. Given that the insurance is based on a rainfall index, it is the amount and timing of rainfall that triggers the insurance payouts. Therefore, the transaction costs are strongly reduced since data monitoring is limited to observed rainfall and does not include measurements of households' individual crop yields. In addition, when payouts are only associated with rainfall data, the risks of adverse selection and especially of moral hazard are reduced since the behavior and characteristics of households do not affect insurance payouts. Another major advantage of index-insurance is the rapidity of insurance payouts, which are likely to be valued by the index-insurance takers, which are often poor and resource-constrained households.

Regardless of the advantages described above, there remain constraints in increasing the coverage of index-insurance. The concept of index-insurance is new and difficult to understand for households as insurance takers (Helmuth et al., 2009), therefore resources have to be invested in explaining it to them. Without good knowledge of the index-insurance product, it is likewise difficult to build confidence and trust in it. This kind of trust has been termed strategic or knowledge-based trust (Miształ, 1996; Seligman, 1997), and it makes households more likely to endorse strong standards of moral behavior and to be willing to pay more for a product. Knowledge-based trust helps to solve problems of collective action by reducing transaction costs. In the context of insurance, Patt et al. (2010) identified trust as an important factor in households' willingness to pay for the product.

The barriers to the taking out of index-insurance have been identified primarily by a body of literature that takes an economic perspective with a focus on the features of willingness to pay, economic efficiency, basis risk and reinsurance (Giné et al., 2008; Giné et al., 2007; Sarris et al., 2006). Basis risk refers to the imperfection between the actual loss and the payout rate that the network receives. Insurance takers can experience losses specific to them, but they will not receive an insurance payout if the index is not triggered. Conversely, insurance takers may turn out lucky if the payouts are above the level of their actual losses. A pilot study of index-insurance in India

found that the take up of insurance decreased with basis risk and that household demand for index-insurance is sensitive to trust in the insurance provider (Giné et al., 2008). In situations in which households trusted the insurance provider, the take-up of insurance was higher. Sarris et al. (2006) estimated the demand for rainfall index-insurance in Tanzania based on willingness to pay and found that those households who use their own savings to cope with income losses caused by the lack of rainfall are more interested and more willing to pay for rainfall insurance compared to those households who use informal networks to cope. The reluctance to take out insurance may be related to households' different liquidity constraints and the opportunity costs of the insurance. But attention must also be given to trust, social norms and relationships in order to emphasize the potential to explore the prospects for accessing insurance takers, or households, through existing informal networks that households are already familiar with. The study from India (Giné et al., 2008) found participation in networks to be strongly correlated with decisions to take out insurance, since the members of networks were more likely to take out insurance if a larger number of other members also bought it.

In conclusion there are a number of obstacles to the take-up of index-insurance. Trust in the insurance provider is an important challenge, and a lack of trust may to some extent be related to a lack of understanding of the product. Trust can be built up by providing the insurance through channels in which the household already has confidence (Giné et al., 2008). Trust is also closely related to the problem of basis risk. If basis risk is minimized, households will gain trust and confidence in the coherence between weather patterns and payouts. These obstacles motivate the following section to look into the fields of social capital and informal networks, given that trust is an integral part of the former.

2.2 Informal networks and social capital

Social groups in communities can be characterized as informal institutions or networks that facilitate collective action. Woolcock (1998, 2001) introduced the basic idea that friends, family and neighbors constitute an important asset that can be relied on in times of a lack of income or sudden or unexpected expenses. This asset is also called social capital. The literature distinguishes between structural social capital and cognitive social capital, two forms of capital that may reinforce each other but that also exist without the other (Uphoff, 2000). Structural social capital facilitates information sharing, collective action and decision-making through established roles, social networks and other social structures. Cognitive social capital encompasses more intangible elements such as shared norms, values, reciprocity and trust.

The social capital theory offers a pragmatic approach which merges economic and social theory. The approach assumes that households are rational but also governed by social norms and cultures. This assumption interferes with the perceptions of individuals in traditional economics as being rational and organized only in accordance with economic incentives. In addition to economic incentives such as the option to share unexpected or extraordinary costs related, for example, to sickness, burials or a wedding, being member of an informal network is motivated by pre-existing interpersonal relationships. It is especially in a situation characterized by a lack of trust in, or absence of, effective market mechanisms that an informal network becomes a valuable source for households to access risk-sharing constitutions. Effective market mechanisms are central to any market transaction and, if households lack trust in existing institutions, they will not be willing to rely on the institutional arrangements alone. Well-functioning markets go hand in hand with households' trust in institutions. When households trust institutions, Uslaner (2002) calls the trust involved 'generalized trust'. Here households believe that most households share common values and are willing to trust strangers who may outwardly seem quite different from themselves. A household's trust is an integral part of social capital and is present in situations in which there is confidence in other households, even though

that there exist uncertainties regarding other the behavior of households and their risks. Uslaner calls trust where households have faith in other households but only those in their own network ‘particularized trust’ (Uslaner, 2002). Particularized trust is embedded in informal networks in which households not only seek profit maximization but also aim to minimize risks by sharing them. The network creates access to risk-sharing arrangements through personal relations with other members of the network. Cassar et al. (2007) show that particularized trust or personal trust between group members and social homogeneity are more important for group loan repayments than general social trust or acquaintanceship between members.

One feature of informal networks is that within a network there will be a high flow of information among members (De Weerd, 2004). This includes information on members’ respective risks, their yields and their production inputs. Another characteristic of informal networks is that a network is embedded within larger social and ecological systems (Putnam 1995, 2000; Putnam et al., 1993). By making the assumption that the members of a network are from a restricted geographical area, the members of the same network can be expected to experience the same complexities in their livelihood productions. This may be related to a number of factors, including soil fertility, market access, institutional setting and not least weather patterns. As a consequence of these complexities, the majority of network members are exposed to the same production risks and will be exposed to virtually the same weather patterns, and the network will most likely experience hardship at the same time if, for example, a drought hits the area. In such a situation, the members of a single network will experience difficulties in sharing risks, since they will not have the opportunity to transfer risk across members when a majority of the members are hit by a shock at the same time. The homogeneity of a network’s members are further emphasized by De Weerd (2004), who points out that close neighbors or households who engage in the same livelihood activities are likely to share information and join the same network. In the absence of informal networks or well-functioning institutions, households will

have to rely on own capability and family remittances and to smooth consumption during times of low or a lack of income.

Informal networks or trusted social relationships can be conceptualized as contracts that rely on flows of information regarding reputations, common norms, trusts and social sanctions. The latter include the threat of being excluded from the network and hence losing the benefits of being part of the network in the future, the threat of damage to a member's reputation and social pressure. As previously mentioned, particularized trust is embedded in informal networks where households have close to full information on the behavior and constraints of the other members. Even with these beneficial characteristics of informal networks, their limitations become clear in the case of covariate shocks, where there is a lack of ability to share risks between members. This limitation becomes crucial at a time when climate variability is increasing and will increase the number of covariate shocks in communities. Therefore more formalized insurance schemes are needed in order to strengthen informal networks and their members' resilience to such shocks.

2.3 A collective approach to index-insurance

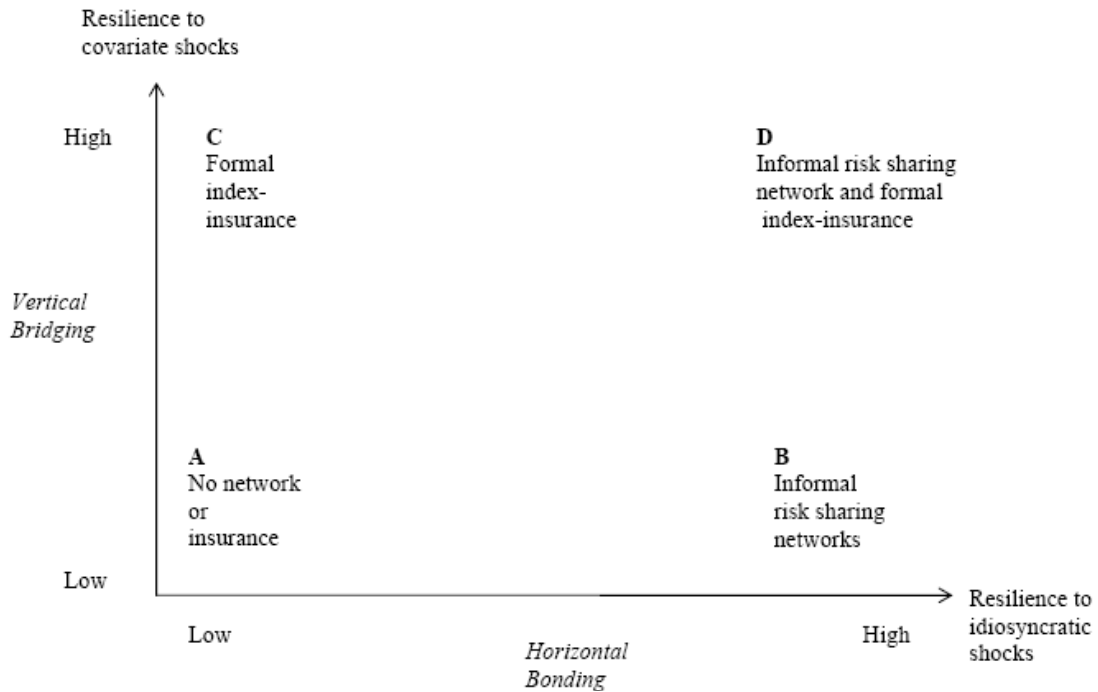
The two previous sections have briefly outlined the potentials and constraints of, first, index-insurance to reduce the production risks of rural livelihoods for resource-poor households, and secondly, the informal networks in which members benefit from risk-sharing. The following discussion suggests that the approach to index-insurance may be improved by adopting some of the strengths that social capital in the form of informal networks constitute. The approach is based on the assumption that, although in development communities there is very often a high level of particularized trust, generalized trust is lacking. Based on the nature of the proposed approach to index-insurance, in what follows it is called 'the collective approach'.

The inefficiency of and failure to take up traditional insurance and index-insurance suggests an argument for building formal index-insurance into existing networks in such a way that the social characteristics of the networks and particularized trust are maintained. This will ensure that network members may continuously benefit from informal risk-sharing along with the index-insurance in order to reduce those correlated weather risks that cannot be shared by the members of the network.

In social capital theory, there are several dimensions of social capital at different levels. These dimensions can be divided into two main kinds of relations, called bonding and bridging (Gittel and Vidal, 1998). Social relations between people within a network or an institution are characterized as bonding, while relations among different networks or institutions are called bridging. This paper concentrates on two aspects of these dimensions, which are related to networks. The first aspect is the consequences of bonding within an informal network at community level and the benefits that arise from these relations. The second aspect is the bridges or linkages between informal networks and formal institutions. In the context of index-insurance, the formal institutions are the index-insurance providers. Bridges between informal networks and formal institutions can be characterized as vertical bridges since the bridging is created between different levels in society. Horizontal bridging occurs in a situation in which networks relate to each other or in which formal institutions collaborate.

Figure 1 illustrates the relationship between the different dimensions of social capital and the resilience to covariate shocks. The figure is structured in accordance with four outcomes associated with informal risk-sharing networks and formal index-insurance.

Figure 1. Dimensions of social capital and resilience to shocks at the household level



The figure illustrates the dimensions of social capital in a community and the resilience of households to idiosyncratic and covariate shocks. The figure was developed by Woolcock and Narayan (2006) and has been adapted by the author to include dimensions of households' resilience to shocks.

The proposed collective approach to index-insurance aims to strengthen the vertical bridging between informal risk-sharing networks and the formal index-insurance institutions. In Figure 1 this is illustrated as a shift from State **C** to State **D**. With such a shift, it is proposed that network members' resilience to weather risks will be strengthened. Starting from the left in Figure 1, the first state, State **A**, represents a situation in which households are not part of any network, whether formal or informal. In this state, the households depend on their own, individual ability to resist a shock. In order for households to improve their resilience to weather risks, they can become members of an informal risk-sharing network or they can formally insure. The second state, State **B**, illustrates a situation in which households participate in informal networks. Nonetheless, the members still have a low level of resilience to covariate shocks affecting virtually the whole network, assuming risk-sharing is a

main coping strategy to get over a shock. Hence the resilience to weather anomalies is low in State **B**. To improve the resilience of network members in State **B** to covariate shocks, the members of the network can break out of the informal network and join a formal index-insurance scheme as illustrated in State **C**. If, however, the risk-sharing network is totally replaced by the index-insurance, the resilience of households to idiosyncratic shocks or shocks which are not covered by the insurance is weakened. An alternative to moving from State **B** to State **C** is for the network members to move from State **B** to State **D**. In order to go from **B** to **D**, a network's members must decide collectively to join the index-insurance scheme and maintain the network's safety net against idiosyncratic shocks while being insured against covariate shocks covered by the index-insurance. In this way, risk-sharing networks that previously only shared risks within the networks are now sharing risks with other networks. Through vertical bridging with a formal index-insurance provider, the networks are indirectly connecting horizontally with other networks. This is well illustrated in State **D**, where a household is bonding with other households within the network at the same time as the network is bridging vertically with a formal index-insurance institution.

The basic idea of the collective approach is that the index-insurance targets an existing informal network as one insurance taker. Therefore the informal network pays one collective premium to the insurance provider and also receives payouts as one insurance taker. It is then up to the network to distribute the payouts based on the information flow within the network. The payout from the network to its members can be made after the index-insurance payout has been triggered. Alternatively, the payout can be made on the basis of internally agreed conditions in the network. Such conditions could, for example, be lower payouts based on a lower trigger than the formal index-insurance in such a way that the payouts will occur more frequently. Alternatively the internal payouts can be based on more traditional insurance conditions such as actual yields. The approach can thus be seen as a collective approach since the network will formally act as one insurance taker. It is argued in

the following that this construction of index-insurance will overcome the critical obstacles related to trust and basis risk associated with the provision of index-insurance, as described in Section 2.1.

Assuming that information flow is high in informal networks, it will reduce transaction costs and create trust. A cost reduction will come about in a situation in which a network distributes an insurance payout which is given to the group as a collective payout. With relatively low monitoring and management costs, a network facilitator has access to information on network members' production inputs, expected yields and actual yields. Therefore, networks gain from the major informational advantages involved in identifying who needs assistance and when. On this basis, insurance payouts can be calculated and disbursed rather quickly due to the close relationship between network facilitator and network members. From the literature, a rapid payout has shown to contribute significantly to establishing the trust of insurance takers in the functioning of the index-insurance scheme (Giné et al., 2008), while the rapid disbursement of payouts has the advantage of being valued by poor and often liquidity-constrained households.

Closely linked to trust, a lack of understanding of insurance schemes and contracts is recognized as another essential barrier to the take-up of index-insurance (Giné et al., 2008; Patt et al., 2010). If insurance takers do not understand the product and contract, trust in the scheme will remain very low and there will be a lack of generalized trust. Relative to project managers outside the network or community, the interaction between a network's facilitator and the households that belong to the network can potentially overcome the lack of trust in the insurance scheme to some extent. Clearly, time and resources must be invested in explaining how the insurance works to the network facilitator and network members. But if the network facilitator is well-informed about the index-insurance, he or she can improve the information that flows to network members and distrust in the institutions can be circumvented. Generalized trust can be strengthened further by the reduction of basis risk. Due to the high information flow within a network, the network facilitator should be able to

administer insurance payouts fairly well. The problem of basis risk may not be completely eliminated, but in a situation in which a network administers the distribution of a collective index-insurance payout, the network facilitator will have virtually full information about production inputs and both expected and actual crop yields. As a result, the insurance payout could come close to actual losses for a relatively low cost. Therefore, using the informal networks as a collective insurance taker will facilitate access to outcomes of index-insurance which would not be feasible with a traditional individually targeted approach. The presence of particularized trust within the networks will be utilized, and the lack of generalized trust of an insurance provider will be overcome through bridging the whole network collectively with the provider.

As described in Section 2.2, networks are embedded within ecological systems. This implies that, in order to make the index-insurance economically feasible for the insurance provider, the participating risk-sharing networks cannot be exposed to correlated weather patterns. If exposure for the insurance takers – the networks – is correlated, the payouts at one time will be too comprehensive for the insurance provider. Therefore it is necessary for the index-insurance scheme to include several networks from a larger geographical area that does not experience the same weather patterns. If a larger number of networks with different weather patterns participate in the same index-insurance scheme, the risk of losses will be transferred over several years and across a wide number of networks.

Although there are numerous advantages in targeting networks as insurance takers, the experience of community-based health insurance shows that there can be several disadvantages to targeting networks under certain settings (Kamuzora and Gilson, 2007; Tabor, 2005). Amongst other problems, targeting networks may lead to or increase conflicts and divisions within the community or network. This may, for example, be the case if the network is exploited to serve the interests of the better off households. This could be the case where there is a majority of better off households in the network and they decide to exclude a number of households for some reason,

for example, that a number of members are carrying greater risks than the majority of the network's members. In such a case, strengthening networks by providing access to index-insurance can potentially make some households worse off if they are excluded from the network when compared to a situation with solely informal networks.

3. A collective approach to index-insurance: the case of Tanzania

Section 2 proposed a collective approach to index-insurance in order to increase the take-up of insurance among resource-poor rural households in developing countries. This section will illustrate the potential for applying a collective approach to index-insurance. As a case study, the focus is on Kagera, a region in the northwestern part of Tanzania situated by the shores of Lake Victoria.

The aim of the assessment is threefold. First, the prevalence of network participation is identified as a way of assessing existing social capital. Secondly, a potential institution that can provide index-insurance is identified. Thirdly, correlations of rainfall amounts across the districts in the region are estimated in order to assess the potential for transferring risk among various networks in different geographical areas.

3.1 Case study area

The population of Kagera is approximately two million people (URT, 2002) with varying population densities between the six districts of Biharamulo, Bukoba Rural, Bukoba Urban, Karagwe, Muleba and Ngara. The rural population rely for their livelihoods primarily on rain-fed annual crops such as maize, sorghum and tobacco in the south and on producing bananas and coffee in the north. Like other farmers in Sub-Saharan Africa, rural households in Kagera are facing high fluctuations in yields

caused by weather-related risks, including droughts and floods (De Weerd, 2008). These risks are aggravated by increasing variability in known weather patterns caused by climate change. The existing rainfall pattern in Kagera is bimodal, with annual rainfall ranging from 1000 to 2000 mm. The rainy seasons are defined as March-April-May (long rainy season) and October-November-December (short rainy season). The recorded data show that in the long rainy season Kagera receives on average 41 percent of total annual rainfall, while during the short rainy season it receives on average 32 percent. The remaining rain falls mainly in January and February.

3.2 Data

The analysis is based on data from the Kagera Health and Development Survey (KHDS) for 2004, which covered over 2,700 households. The KHDS was originally adapted from the World Bank's Living Standards Measurement Study (LSMS) questionnaires and consists of over 2,700 households. HIV/AIDS has been a major problem in Kagera, and a main aim of the KHDS was to collect data that can be used to analyze the impact of illness (Beegle et al., 2006).

One of the questions in the KHDS questionnaire concerned informal organizations. All respondents were asked if they or members of their households participate in risk-sharing informal networks on which they can rely for assistance in times of illness, funerals and other hardship or events. Those respondents who answered yes were asked to name the networks they participate in and to define the main hardships for which each of the groups can provide help.

One concern that arises using this data set is consequently that the survey design included an over-sampling of households that were considered to be at risk based on the following criteria: those with a sick adult and/or those households that had

experienced an adult death in the past two years at the time the first household was listed (about six months before the first survey round). It is possible that households that have experienced a death in earlier years become members of specific networks such as burial societies. However, the 2004 wave used in the analysis was collected thirteen years after the first wave, raising the possibility that the households in question may have overcome the difficulties caused by a death or illness. Nonetheless, this must be acknowledged as a limitation of the analysis.

Rainfall data were obtained from the KHDS. The data cover the period from 1980 to 2004 for rainfall stations in each of the six districts in the region. A number of observations from 2004 are lacking for Biharamulo, Bukoba Urban, Ngara and Muleba. In addition, Biharamulo lacks three observations from 1999 and one each from 1993, 1997 and 2000. Bukoba Rural lacks one observation each from 2001 and 2004. As a result 2004 was removed from the analysis, while the remaining missing observations were accounted for during the analysis.

3.3 Results and discussion

3.3.1 Informal networks

The target groups for a collective index-insurance include existing informal networks and, alternatively, semi-formal networks. A semi-formal network is a network which is regulated through registration or licensing but is run by its own members. In Kagera, households have strengthened self-financing mechanisms through a variety of informal networks, of which De Weerd (2001) identified 47 in one single community in Kagera.

As a proxy for the prevalence of social capital, Grootaert and Van Bastelaer (2001) propose three types of indicators: membership in local networks, trust and adherence to norms, and indicators of collective action. Given the assumption that the KHDS

data is representative of households in Kagera, the statistics in Table 1 and 2 show that almost half of the households in Kagera participate in between 1 and 5 informal networks. These figures exclude relations with family and relatives.

Table 1. Participation in networks

Variable	Frequency	Percent
Non-Members	1,272	52
Members	1,184	48
Total sample	2,456	100

The table shows the participation of households in informal networks from the Kagera sample. Source: own calculations based on KHDS.

If households participate in informal networks, the data in Table 2 indicate that households will be likely to participate in more than two networks. The informal networks mainly support costs related to funerals (90 percent of groups), illness (50 percent of groups) and weddings (43 percent of groups). Being a member of one of these informal networks involves the payment of premiums in small amounts in return for predetermined payouts when a specific event occurs.

Table 2. Membership numbers

Variable	Obs.	Mean	Std. dev.	Min	Max
Memberships	2235	2.43	1.19	1	5

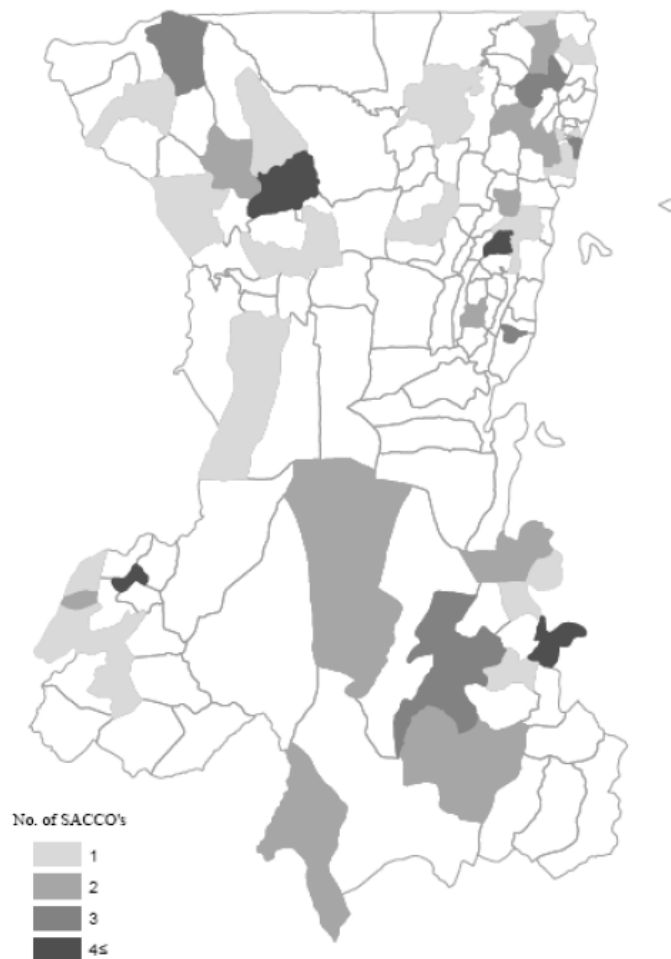
The table shows the number of total memberships in informal networks in Kagera.

Households are members of up to 5 networks. Source: own calculations based on KHDS.

In addition to the informal networks, there are 97 Savings and Credit Cooperative Societies (SACCOs) distributed throughout Kagera (Bank of Tanzania, 2005). A SACCO is a semi-formal network and a form of cooperative. SACCOs depend largely on members' own financial arrangements and are autonomous and self-regulating cooperations. They are owned and controlled by their own members with the aim of fulfilling members' economic and social needs, and for many households membership in a SACCO is a valuable safeguard against unexpected illness, accident or family death. SACCOs provide credit and savings products for their members in

cooperation with a formal bank in Tanzania. There are about 1,400 registered SACCOs throughout Tanzania, with the networks ranging from community-based initiatives with members who work in the informal economy to workplace-based networks (Bank of Tanzania, 2005). The distribution of SACCOs in Kagera is shown in Figure 2.

Figure 2. Distribution of SACCOs in Kagera region



Own computation based on (Bank of Tanzania 2005).

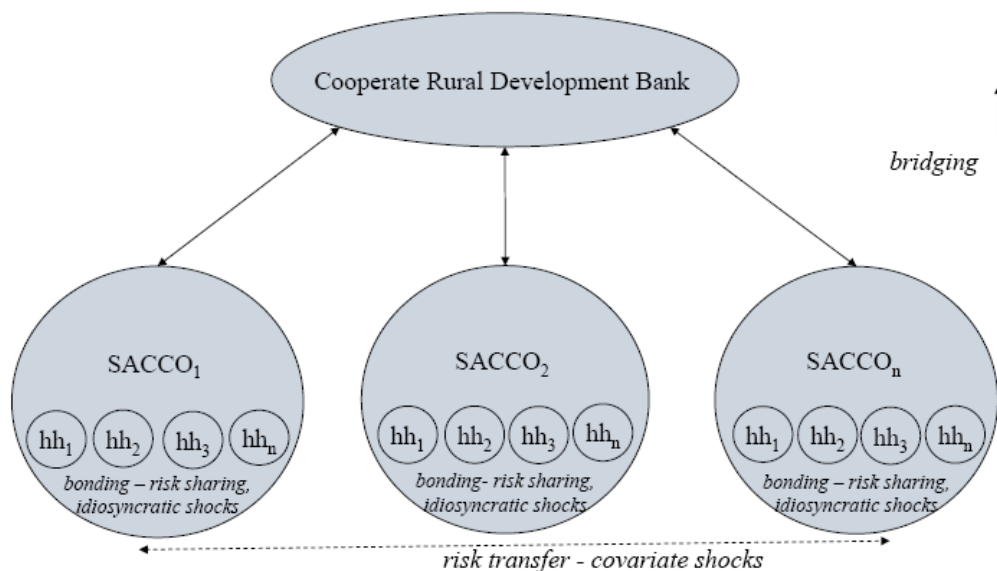
Identifying networks with a strong trust base appears to be key to the success of collective index-insurance. Group members have to trust that others will fulfill their obligations and discuss difficulties when they are unable to, and they must also have

trust in the motives and activities of those who lead and account for the group. Since the SACCOs in Kagera are well established and have a large number of members, they present an advantageous entry point for the provision of collective index-insurance to rural households in Kagera. The literature indicates that households who already have trust in the SACCOs will be more likely to trust the insurance and henceforth be more willing to pay for it (see Sarris et al., 2006). Using SACCOs to provide collective index-insurance is further supported by a study by GlobalAgRisk (2009) showing that the success of an insurance programme is likely to be higher if potential insurers already have some experience with formal financial transactions. As already mentioned, the SACCOs already engage to various degrees in credit and savings products for their members. Nevertheless, as with any other intervention, using semi-formal networks to provide collective index-insurance should consider existing or emerging problems related to poor management, corruption and the misuse of resources, a lack of working capital, a lack of cooperative democracy and education, and the weakness of supporting institutions. These problems can be addressed to a large extent through the capacity-building of both network facilitators and ordinary members.

3.3.2 Bridging between informal networks and a formal index-insurance provider in Kagera

A prerequisite to make the insurance scheme function well is a well-established institution to interact with the informal networks. One potential insurance provider in Kagera region is the commercial bank Cooperate Rural Development Bank (CRDB), which is already cooperating with SACCOs on micro-financing, including savings and credits.

Figure 3. Bridging, bonding and risk transfers in Kagera with a collective approach to index-insurance



Naturally, the ability of SACCOs to reduce covariate risks in rural areas is limited. This limitation is a result of the widespread impacts of community-wide downturns that affect the majority of a network’s members and consequently reduce their ability to share risk internally within the network. To reduce the risk of covariate shocks, SACCOs need to connect with other networks in order to share and transfer risks between time and space. The establishment and strengthening of these risk-sharing bridges between a larger numbers of SACCOs can be facilitated by each SACCO linking up with an index-insurance provider. This is illustrated in Figure 3. In a situation in which SACCO members decide to participate collectively in an index-insurance scheme, the households that belong to the SACCO will now change their situation from State **B** to State **D** in Figure 1. If one index-insurance provider covers a larger geographical area with a larger number of networks, this has the potential to increase the economic feasibility of providing the index-insurance, a result of spreading the risk over a larger area with different weather patterns. The SACCOs will therefore implicitly be bridged through the index-insurance provider.

3.3.3 Weather correlations

A necessary condition to make the index-insurance economically feasible for the index-insurance provider is uncorrelated weather patterns for the insured networks. The index-insurance relies on negative meteorological events to trigger payouts. Negative weather events can be related to: a) minimum temperature for a specific period of time; b) amount of rainfall during a specific time period, whether excess rain or a lack of rain; and lastly c) attainment of a certain wind speed for hurricane insurance. Since rainfall is the main uncertainty in Kagera and water deficits adversely affect crop yields in rain-fed agriculture, rainfall will be used as the insurance trigger to illustrate this example.

The quality of rainfall data is of great significance in reducing basis risk. The six districts in Kagera are covered by 21 weather stations. The distribution of stations between districts is shown in Table 3. A comparison of the distribution of weather stations reveals that Bukoba Rural and Karagwe are best off in terms of the relationship between weather stations and SACCOs.

Table 3. Main characteristics of Kagera region

	Biharam ulo	Bukoba Rural	Bukoba Urban	Karagwe	Muleba	Ngara	Kagera total
Pop. density (person/km ²) ¹	46	73	1015	56	155	76	237
Size (km ²) ²	8,938	5,450	80	7,558	2,499	4,428	28,953
Weather stations ³	2	7	1	5	4	2	21
SACCOs ⁴	23	19	14	16	15	10	97
Annual total rainfall (mm) ⁵	1243	1708	1961	1400	1637	1008	1508

The table shows total and district characteristic for Kagera. Data is based on ^{1,2}URT (2002), ³KHDS,

⁴Bank of Tanzania (2005), ⁵long term average 1980 – 2004, KHDS.

In order to examine the feasibility for the insurance provider to offer index-insurance in Kagera, whether the district's annual rainfall amounts are correlated must be tested. To avoid the insurance providers being financially exposed due to highly correlated risks between insurance takers, the size of the area being offered insurance must be of a certain size to cover different rainfall patterns. If there is a correlation between failures of rainfall in different areas, insurance payouts will be triggered at the same point in time. In a situation in which payouts are made to all insurance takers at the same time, an insurance provider will be prevented from transferring risks among insurance takers. Consequently, most insurance providers will not be able to absorb such correlated risks, and it will not be financially viable to provide insurance to the insurance provider. Table 4 shows that the level of correlation differs from district to district. For example, the amount of rainfall in Bukoba Urban is only correlated with the amount of rainfall in Ngara. On the other hand, the amount in Karagwe is correlated with amounts in all districts except Bukoba Urban. Nonetheless, as long as the correlation is only between a limited number of districts, it will remain possible for an insurance provider to transfer risks. An equivalent correlation analysis can be carried out on a seasonal or monthly basis.

Table 4. Correlation coefficients matrix for annual rainfall, Kagera districts 1980-2003

Parameter	Biharamulo	Bukoba		Karagwe	Muleba	Ngara
		Rural	Urban			
Biharamulo	1.000	0.438*	0.197	0.551*	0.680*	0.236
Bukoba Rural	0.438*	1.000	0.194	0.656*	0.445*	0.325
Bukoba Urban	0.197	0.194	1.000	0.118	0.178	0.436*
Karagwe	0.551*	0.656*	0.118	1.000	0.548*	0.447*
Muleba	0.680*	0.445*	0.178	0.548*	1.000	0.078
Ngara	0.236	0.325	0.436*	0.447*	0.078	1.000

Own computations based on KHDS. * means significance at 5 percent level

The situation analysis of the potential for applying a collective approach to index-insurance in Kagera suggests that potentially there are favorable conditions for applying such an approach to insurance in this area. The commonality of households

being members of informal networks indicates the existence of social capital within these communities. Taking this together with the number and distribution of SACCOs, this is promising for applying the collective approach in this area. Even though SACCOs are not present in all districts, they are established in those districts with the highest population densities and hence should be accessible to the majority of households. However, this assumes that SACCOs are equally accessible to all households that wish to become members of the relevant network. Lastly, the rainfall statistics for Kagera showed risks to be correlated only among some of the districts in the region. This suggests that a lack of rainfall will only affect parts of the portfolio at the same time. Risk can therefore be transferred into the insurance market and be diversified into the Kagera regional portfolio of insurance risks.

4. Conclusions

With the increase in number of climate-related shocks that affect whole natural resource-dependent communities, there is an urgent need for improving the resilience of both communities and households within these communities to such shocks. One way to strengthen this resilience is to reduce risks and uncertainties in the livelihood production of natural resource-dependent households. This can be done through formal insurance schemes which can transfer risks between time and space. This paper has argued for a collective approach to index-insurance. In its current form, the participation of households in an index-insurance scheme is discouraged by the problem of their limited trust in the scheme. Trust is associated with the issue of basis risk, where rainfall patterns experienced by households do not correspond with the index-insurance payouts. To overcome this problem, this paper has argued that index-insurance should target existing networks as collective insurance takers. Using such an approach, evidence from social capital theories suggests that relations between the members of a network will build trust in the index-insurance scheme if the scheme is introduced by a well-known source, for example, the network's facilitator. At the

same time, the insurance scheme within the network may work as a more traditional insurance scheme, with payouts being based on actual crop yields. This has prospects for reducing the problem of basis risk. The potential for applying a collective approach to index-insurance was demonstrated with a case study from northern Tanzania.

The idea of using informal networks as a collective insurance taker is not totally new. Micro-insurance, a relatively new intervention that addresses marriage, celebration of childbirths, sickness and burial expenses, is often based on group arrangements. Nonetheless the approach is new in the context of rural insurance and when related to index-insurance. Evidently, not all informal networks are equally suitable for affiliation to an index-insurance scheme, given differences in membership and leadership structure, and in the history, longevity and nature of activities. Studies that identify which features make informal networks more favorable to index-insurance will provide valuable information for future recommendations. Given the lack of such knowledge at present, the recommendations regarding policy implications will be of a more general nature. Nonetheless, the paper has raised conceptual arguments for including social capital aspects in the design of index insurance. This, it is argued, will increase the take-up of index-insurance and implies a decrease in the number of households that experience a substantial decrease in income due to a climate-related harvest failure. An increase in the take-up of index-insurance would imply that households are avoiding using savings for consumption purposes, while maintaining their respective levels of consumption. In addition, a strategy such as the adoption of low return-low risk crops may be avoided, as will a situation in which households send their children to work instead of to school in order to supplement family income.

Certainly, collective index-insurance is not the whole solution to improving the resilience of households and communities to climate-change impacts and climate variability in general. Insurance is one tool of many in a portfolio of strategies to manage and reduce risks and uncertainties. These strategies include credit and saving

programs, income diversification, and adjustments to crop and water management practices.

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Paper 3



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The Health Impacts of Climate Change: A Study of Cholera in Tanzania

Sara L. M. Trærup^{1, 2*}, Ramon Arigoni Ortiz³ and Anil Markandya³

Increased temperatures and changes in patterns of rainfall as a result of climate change are widely recognized to entail serious consequences for human health, including the risk of diarrheal diseases. Indeed, there is strong evidence that temperature and rainfall patterns affect the disease pattern. This paper presents the first study that links the incidence of cholera to environmental and socioeconomic factors and uses that relationship to predict how climate change will affect the incidence of cholera. Specifically, the paper integrates historical data on temperature and rainfall with the burden of disease from cholera in Tanzania, and uses socioeconomic data to control for impacts of general development on the risk of cholera. Based on these results we estimate the number and costs of additional cholera cases and deaths that can be attributed to climate change by year 2030 in Tanzania. The analyses are based on primary data collected from the Ministry of Health, Tanzania, and the Tanzania Meteorological Agency. The result shows a significant relationship between cholera cases and temperature and predicts an increase in the initial risk ratio for cholera in Tanzania in the range of 23 to 51 percent for a 1 degree Celsius increase in annual mean temperature. The cost of reactive adaptation to cholera attributed to climate change impacts by year 2030 in Tanzania is projected to be in the range of 0.02 to 0.09 percent of GDP for the lower and upper bounds respectively. Total costs, including loss of lives are estimated in the range of 1.4 to 7.8 percent of GDP by year 2030. Lastly, costs of additional cholera cases and deaths attributed to climate change impacts in Tanzania by the year 2030 largely exceed the costs of preventive measures such as household chlorination.

Keywords: climate change; health impacts; adaptation costs; Tanzania

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1. Introduction

With continuous and increasing rates of morbidity associated with waterborne diseases, especially in Sub-Saharan Africa (Kosek et al., 2003), this group of diseases is potentially an enormous economic burden leading to significant direct costs to the health sector and to households, and indirectly by means of lost time allocated to work, school and other productive activities, to the economy and society at large.

Water-related diarrheal diseases, including cholera, are widespread in areas where water resources are scarce and the majority of diarrheal diseases can be attributed to environmental factors such as unsafe drinking water, poor hygiene and lack of sanitation (Prüss-Üstün and Corvalán, 2006). Floods caused by heavy monsoons can contaminate drinking water with the bacterium. In droughts, the bacterium can grow more easily in stagnating water in ponds and rivers. Cholera has been found to vary with climate fluctuations over long time periods (Pascual et al. 2002) and recent studies have associated temperatures and rainfall anomalies with diarrhea and cholera, and these stress the role of climate variability in transmission of diarrheal diseases. (Singh et al. 2001; Koelle et al., 2005; Checkley et al., 2000; Fernández et al., 2009). Furthermore, there is a rising emphasis on quantifying health impacts from climate change (Campbell-Lendrum and Woodruff, 2007; McMichael et al., 2004). The projected climate change impacts for Sub-Saharan Africa indicate increased rainfall variability, increased temperatures as well as prolonged droughts (Christensen et al., 2007). Therefore, the magnitude of climate change related health impacts over the next few decades will largely depend on the effectiveness and timing of adaptation measures. For this purpose, decision makers and national governments need information on the extent of damages attributed to climate change, the financial resources needed for adaptation, and on what damages can be avoided through proposed adaptation measures. Also, the World Health Organization (WHO) has examined the global burden of disease attributable to climate change up to year 2000, and on this background it has emphasized that planning health adaptation to climate change impacts will require detailed assessments of national vulnerabilities to specific health risks (WHO, 2002).

There are two main types of adaptation measures to climate change: *reactive*, which are measures taken in response to climate change, and *preventive* measures taken in advance of climate change to minimize or offset adverse impacts. Suggested adaptation strategies for diarrheal diseases concentrate on the reduction of vulnerability to current climatic events, as well as the inclusion of adaptation policies in planning for long-term sustainable development. Measures for the prevention of cholera mostly consist of providing clean water and proper sanitation to populations who do not yet have access to basic services. Health education and good food hygiene are equally important. Also, strengthening surveillance and early warning greatly help in detecting the first cases and put in place control measures. Reactive measures include treatment of the disease to reduce the negative impacts.

There exist several reviews and studies of costs of health intervention programmes which address the prevention of climate-related diarrhea and cholera (Clasen et al., 2007; Banerjee et al., 2007; Jeuland and Whittington, 2009; Hutton and Haller, 2004; Markandya and Chiabai, 2009). These studies focus on planned interventions (undertaken in a non-climate change related context) and provide indicators and cost estimates that can be applied in a climate change context, since interventions in principle are the same. However, the figures provided must be considered as a lower bound of total costs of adaptation since indirect costs such as loss of earnings, life years lost and disability are not included in these estimates. Recently, studies have therefore turned to focus on the costs of specific interventions for

preventive and reactive adaptation measures, including those for diarrheal diseases, related to future climate change (Ebi, 2008; UNFCCC, 2007). There remains, nevertheless, very little information from the literature on the costs of health adaptation in different climate change scenarios, especially for developing countries. This could be accredited to adaptation being a relatively new field, and the difficulties with quantification of costs, especially in developing countries, due to lack of data and long-term reporting on disease and climate variables.

According to WHO, improvements in water supply and sanitation are the most sustainable approach for prevention against cholera and other waterborne epidemic diarrheal diseases (WHO, 2008b). A pressing challenge is therefore the need for improved water supply. A general main development objective is to increase access to clean, affordable and safe water and sanitation and to reduce vulnerability from environmental risk. Nonetheless, the WHO projections of health burden attributable to diarrheal diseases for 2030 predict, for sub-Saharan Africa, an increase in relative number of incidences. This is despite socio-economic development and increased coverage of water and sanitation (WHO, 2008a). The WHO estimations considered a number of environmental and socio-economic variables with a mix of country and regional level inputs.

This paper provides new evidence on the health impacts from climate change on the incidence of cholera as complimentary information to previous estimates of burden of disease attributed to diarrheal diseases in sub-Saharan Africa. The analysis draws on primary data sources to estimate the relationship between climate variables and cholera in Tanzania, and uses these results for projections of future burden of cholera attributed to climate change by year 2030 in Tanzania. These results provide a basis for estimating costs of residual cases of cholera attributed to climate change, including information on the expected future cases and loss of lives, and on the consequences to public health expenditures as well as the additional costs related to loss of lives. The results draw attention to the fact that neglecting climate variables will result in a serious underestimation of the projected number of cholera cases which can be expected by 2030. In addition, economic costs of climate change impacts on burden of cholera will be greatly underestimated by ignoring such changes in environmental factors.

The analysis in this paper is divided into two main elements. Firstly, to quantify the extent of impact from climate change on cholera incidences, the paper starts by analyzing the relationship between temperatures and precipitation and cases of cholera. These results are then used to establish scenarios as indicative measures of potential climate change impacts to cholera distribution in Tanzania by 2030. The number of cases, deaths and burden of disease in terms of disability-adjusted life-years (DALY) are computed. Finally, the second part of the paper estimates the costs associated with residual health impacts attributed to climate change by year 2030.

2. Methodological Issues

In order to analyze the magnitude of burden of cholera attributable to climate change, it is useful to decide on different scenarios that the analysis will build upon. For this purpose, climate change predictions for the specific locality as well as population growth and economic development will need to be considered. The following two scenarios are suggested:

Scenario C₀, year 2030, is the baseline scenario where implications from climate change to disease patterns are not integrated in the analysis. The scenario includes assumptions of economic

development and hence implicitly assumes an improved health care sector as a result of increasing GDP and other socio-economic developments which are expected to positively influence on the health sector performance. Socio-economic development is also assumed to include preventive measures such as water and sanitation programmes. As for Tanzania, the strategy for the water sector includes a long- term target of nearly universal access to clean and safe water by 2025 (URT, 2000). The relative burden of disease attributed to cholera in 2030 compared to year 2008 is expected to be lower due to improvements in health sector performance and increased water and sanitation coverage (basic preventive adaptation measures).

Scenario C₁, year 2030, builds on *Scenario C₀* and estimates the number of cholera cases and deaths considering projected climate change impacts on cholera cases and deaths based on the results of an econometric analysis of the relationship between environmental and socioeconomic variables. The additional number, N_{2030cc} , of incidences of cholera attributed to climate change impacts by year 2030 are hence estimated as

$$N_{2030cc} = \text{Scenario}_{C_1} - \text{Scenario}_{C_0} \quad (1)$$

The estimations are based on the same main assumptions. The predicted exposure to climate change in Tanzania by year 2030 is carried out for a 1 and 2 degree Celsius temperature increase, respectively, based on the IPCC (2007) predictions. Secondly, socio-economic development is assumed to increase water and sanitation coverage and, thirdly, it is assumed that population projections for year 2030 will be in line with the UN projected population (UN, 2008) for Tanzania and increase from 37,600,000 year 2004 to 75,498,000 people by year 2030. Lastly, projected number of cases and deaths without considering climate change impacts are estimated from WHO Global Burden of Disease (GBD) study (WHO, 2008) which includes projections for diarrheal diseases for Sub-Saharan Africa by 2030.

In the following, *Scenario C₀* and *Scenario C₁* form the basis for estimating the incidence of cholera in Tanzania by year 2030 and the number of residual cases attributed to climate change. The costs of reactive adaptation, which in the case of cholera is treatment, are equal to the costs of treatment of the additional number of cases attributed to climate change.

3. Analysis of Health Impacts

3.1 Quantification of the Health Impacts

To assess the burden of cholera attributed to climate change, the magnitude of climate change for the specific location is required. This is both in term of present climate, its variability and how climate variables potentially are expected to change over time. For this matter, an emphasis on time perspective and geographical position are important to assess local and sectoral impacts. Subsequent work by various international experts including climate modelers has assessed at a relatively detailed level the potential climate change impacts in different parts of Africa (Christensen et al., 2007). Among the conclusions that emerge is an agreement across most models to the effect that there will be a tendency to increased precipitation in the winter months in East Africa with future climate change, but that this may also be combined with an increased intensity of rain in shorter periods and drought in other periods. Moreover, temperatures in Tanzania are predicted to increase within the range of 1-2 C° by year 2030.

3.1.2 Health Outcome for Cholera Attributed to Climate Change

Cholera, which is a diarrheal disease, is primarily waterborne and epidemics may be boosted by extreme climate conditions that enable the waterborne bacterium *Vibrio cholerae* to be spread more easily. High and mean monthly temperatures are found to be strongly associated with increased episodes of diarrheal disease in adults and children (Checkley et al., 2000; Speelman et al., 2000; Lama et al., 2004; Singh et al., 2001). Evidence is also found that both droughts and floods increase the spread of the cholera (Koelle et al, 2005). In order to investigate a potential relationship between climate variability and cholera cases and deaths we used Poisson regression analysis (similar to others in the field – see e.g. Singh et al., 2001; Kuhn et al., 1994; Tango, 1994). A Poisson regression is used to fit models of the number of occurrences or counts of an event (dependent variable) assuming they follow a Poisson distribution (where the mean and variance are identical). The model estimates the expected value of the dependent variable as a log-linear function of a set of independent variables and regression parameters (Kuhn et al., 1994).

Historical data on burden of disease attributed to cholera were collected from the Ministry of Health, Dar es Salaam. Cholera cases in the whole country were available per month between January 1998 and December 2004, while cholera cases and deaths were available annually for all of Tanzania (1977 to 2004) and for 21 regions of the country (1998 to 2004). The climate variables – rainfall and temperatures – represent the average of 19 weather stations throughout the country. In addition to climate and health variables, socioeconomic data were gathered for the datasets containing data per year. The models are of the general form:

$$\ln(\text{health variable}_t) = \alpha + \beta_1.(\text{climate variable}_t) + \beta_2.X_t + \varepsilon \quad (\text{time series}) \quad \text{or} \quad (2)$$

$$\ln(\text{health variable}_{it}) = \alpha + \beta_1.(\text{climate variable}_{it}) + \beta_2.X_{it} + \varepsilon \quad (\text{panel data})$$

Where health variable is the incidence of cholera cases or deaths in period t (month or year); climate variable represents rainfall or temperature; and X is a vector of socioeconomic factors that may explain the health variable (population growth⁴, GDP⁴, water and sanitation coverage⁵, literacy rate⁵ and cassava production per capita⁶). For each dataset several different model have been tested with specifications combining the regressors. The preferred models are chosen according to the level of significance of regressors in each model and the results of a previous correlation analysis of all variables in our datasets. Details of our preferred models are given in Annex 1.

The results using the dataset gathered per month showed a positive and significant association between cholera cases and temperature. A time trend variable was integrated in the model as a proxy to other socioeconomic variables that were absent in this dataset. The relative risk, which represents the relative change in the dependent variable given a one-unit change in the explanatory variable, was estimated to be equal to 1.51. In other words, an increase in temperature equal to 1 degree Celsius would increase the risk ratio for cholera cases in Tanzania by 51 percent. Using the annual data for all Tanzania,

⁴ IMF (2008)

⁵ URT (1992, 1996, 1999, 2005)

⁶ FAO (2005)

temperature also better explained cholera cases when GDP per capita was introduced as a control variable. In this model, an increase in temperature equal to 1 degree Celsius would increase the risk ratio for cholera cases in Tanzania by 23 percent. These results were confirmed when using the panel of regions dataset, in which case a 1 degree Celsius increase in temperature was found to increase the risk ratio for cholera cases by 51 percent.

When fitting models for cholera deaths, literacy rates and access to water and sanitation were individually significant in explaining cholera deaths. The number of observations (15) did not allow enough degrees of freedom to fit a model with all climate and socioeconomic variables, but it is certainly worth gathering a longer series of those variables for future analyses. It was also found that cholera deaths are dependent on the number of cholera cases, that is, the higher the number of cases the higher the number of deaths (i.e. the exposure variable is number of cases). The results were statistically significant and exhibited the expected sign for GDP per capita (negative), but also a negative relationship between rainfall (or temperature) and cholera deaths. It may be the case that climate variables have an impact on cholera cases, but do not affect the case fatality rate; the latter might be more related to socioeconomic health conditions.

In order to investigate such claim a linear regression analysis was developed associating deaths with cholera cases while controlling by real income per capita and percentage of the population with water cover. These models presented the expected signs and statistical significance. Cholera deaths increase with cholera cases and decrease when income and the percentage of the population covered with safe water increase. One extra case of cholera in Tanzania is associated with an extra 0.081 deaths when controlling for income and 0.077 when controlling for safe water cover.

These models allow us to forecast the number of cholera deaths associated with estimates of income as well as the number of cholera cases in a scenario where temperatures increase due to climate change. The number of cholera cases can be predicted using the Poisson models associating cholera cases with marginal increases in temperature.

3.1.3 Morbidity and Mortality Related to Cholera Attributable to Climate Change

In this section we analyze the impacts of a temperature increase of 1 to 2 degree Celsius on the burden of cholera, with focus on cases and deaths, in Tanzania by year 2030.

The number of cases attributable to climate change by 2030, $Cases_{2030cc}$, is equal to the number of cases in Scenario C_1 minus the number of cases in Scenario C_0 . The scenarios are characterized as outlined in section 2 on methodology.

$$Cases_{2030cc} = cases_{C_1} - cases_{C_0} \quad (3)$$

The number of cases in each of the scenarios is estimated from the number of projected population year 2030 multiplied by the risk ratio of cholera. The risk ratio varies between the scenarios. For the Scenario C_0 an initial risk ratio of 0.0019 is estimated, based on the WHO projected burden of disease, and for Scenario C_1 , an additional risk ratio attributed to climate change is added to the initial risk ratio. The additional risk ratio is estimated from the relative risk ratio calculated based on the econometric estimations presented in section 2.1.3. The risk ratio of having cholera for each of the scenarios is

presented in Table 1, including for 1 and 2 degree Celsius increase in temperatures by year 2030, respectively.

Table 1. Risk ratios

Scenario year (2030)	Risk ratio
Scenario C ₀	0.0019
Scenario C ₁ (1°C 2030)	
Lower	0.0024
Upper	0.0029
Scenario C ₁ (2°C 2030)	
Lower	0.0029
Upper	0.0044

The table presents the risk ratios for each of the scenarios. For 2 degree Celsius increase in temperature by 2030, the risk ratio = initial risk ratio (Scenario C₀) * additional risk ratio²

The figures for the respective risk ratios are relatively low, but since the risk ratio in Scenario C₀ is somewhat small with a baseline risk of getting cholera only on 0.19 percent, the risk ratio is also small for a 1 degree Celsius temperature increase with an increase of 0.05 to 0.1 percentage point for the lower and upper bound. Nonetheless, the upper bound estimates for Scenario C₁ with a 2 degree Celsius temperature increase is more than twice as much as the estimated risk in the baseline Scenario C₀.

The number of additional cholera deaths attributed to climate change by year 2030, $Deaths_{2030cc}$, is equal to the number of deaths estimated for Scenario C₁ minus the number of deaths projected for Scenario C₀.

$$Deaths_{2030cc} = deaths_{C_1} - deaths_{C_0} \quad (4)$$

The number of cholera deaths for Scenario C₀ is based on the projections in the WHO GBD study, while the number of deaths in Scenario C₁ are calculated from the estimated number of cases in Scenario C₁, as estimated above, multiplied by a case fatality rate of 0.81 based on the econometric results in section 2.1.3. The results of computed cases and deaths are presented in Table 2 for each of the scenarios. The Table also includes estimates of DALYs, which are explained further below.

Table 2. Projected and estimated burden of cholera disease for the different scenarios

	Scenario C ₀ 2030 ⁷	Scenario C ₁ (1°C 2030)		Scenario C ₁ (2°C 2030)	
		Lower	Upper	Lower	Upper
cholera cases	145,174	178,564	219,213	219,634	331,011

⁷ Based on global burden of disease studies, the WHO predicts an increase in diarrheal incidences of 5 percent per degree Celsius increase in temperatures (Campbell-Lendrum and Woodruff 2007). This would result in a number of 7,259 additional cases and 588 additional deaths from cholera attributed to climate change in Tanzania by year 2030. These much lower estimates are, however, based on case studies from Peru (Checkley et al. 2000) and Fiji (Singh et al. 2001) and for diarrheal diseases as an aggregate estimate.

additional cases		33,390	74,039	74,460	185,837
cholera deaths	11,759	14,464	17,756	17,790	26,812
additional deaths		2,705	5,997	6,031	15,053
DALYs	554,691	682,275	837,590	839,199	1,264,761
additional DALYs		127,584	282,899	284,507	710,070

Scenario C_0 is based on the WHO projection for Sub-Saharan Africa. For Scenario C_1 , results are presented for the lower and upper bounds and for a 1 and 2 degree Celsius temperature increase, respectively.

The total number of cases will consequently increase from the projected 145,174 cases to 331,011 with an additional number of 185,837 cases for the upper bound scenario and with a 2 degree Celsius temperature increase by year 2030. For the more moderate scenario with only 1 degree Celsius increase in temperature, still with the upper bound scenario, the additional number of cases will be 74,039. For the most moderate scenario, lower bound and 1 degree Celsius increase in temperature, the additional number of cases attributed to climate change will be 33,390. In regard of deaths, the numbers will increase from the projected 11,759 deaths to 26,812 for the upper bound scenario with a 2 degree Celsius temperature increase. This is equal to an additional 15,053 deaths attributable to climate change. For the most moderate scenario, the additional number of deaths is limited to 2,705.

3.1.4 Disability from Cholera Attributed to Climate Change

Studies that examine associations between climate variables and human health often use additional cases and/or deaths as the main indicator of impact to health. However, in some cases the fatality rate is low or even decreasing with time although the risk ratio is constant or increasing. This is especially true for a developed country but also for developing countries with increasing GDP and thereby increasing health sector development. It may be that incidence rate is dependent on climate variables while case fatality rate is mainly dependent on socio-economic variables (which are also evident from the econometric results above). Therefore, it is considered appropriate to use estimates of DALY to supplement the comparison of estimated deaths and illness in the different scenarios. DALY combines years of life lost (YLL) from premature death, and years of life lived with disabilities (YLD), and is commonly used as an index for comparison of health in studies of disease (Mathers and Loncar, 2005). DALY is calculated as the sum of YLL and YLD:

$$DALY = YLL + YLD \quad (5)$$

where $YLL = N_D * E_x$, N_D is number of deaths, and E_x is life expectancy at age of death. YLD is estimated as $YLD = I * DW * L$, where I is total number of episodes, DW is disability weight, and L is duration of each episode.

To estimate the disease burden, data are needed on number of cases, the demographic distribution of deaths, and duration of episodes, life expectancy, and the disability weight for cholera. The number of cases is available for each scenario as presented in Table 2. WHO estimate the distribution of diarrhea between age groups in sub-Saharan Africa. We assumed that this distribution is the same for Tanzania, and that the age distribution for cholera is equal to that of diarrhea. For each age group, average YLL are calculated for a life expectancy at birth of 63.8 years (both sexes combined) by year 2030 (UN 2008). Disability weight captures valuation of time lived in a non-optimal health state viewed from

societal preferences. The disability weight ranges between 0 (health condition is equivalent to full health) and 1 (health condition is equivalent to death) and the disability weight associated with each health condition is fixed across all social, cultural and environmental contexts (Lopez et al., 2006). The use of disability weight for diarrhea range between 0.02–0.12 (WHO, 2008) and an average 0.07 is used for the estimations in this paper assuming that it would be in the same range for cholera. The estimated DALY's lost from cholera attributed to climate change are presented in Table 2 and the additional number of DALYs ranges between 127,584 and 710,070.

DALY estimates can be valuable for estimating the mean costs of preventive measures per DALY avoided by following the cost-effectiveness approach and reporting the results in terms of DALYs averted for each dollar invested for various interventions.

3.2 Estimation of Health Adaptation Costs

Preventive measures, which in the case of cholera are considered mainly as hygiene, water and sanitation programmes, are assumed to be initiated and implemented in line with general socio-economic development in Tanzania and the national goals of nearly universal water and sanitation coverage by year 2025. These programmes are established outside the health sector, but nevertheless bring large health benefits along with other domestic and productivity benefits in terms of time savings for water collection, increased time for education and leisure activities, and benefits to agricultural and income generating activities (Sanctuary et al., 2005). The impact from climate change on health will lead to increasing benefits from such programmes and, likely, there will be an increase of benefits in terms of saved lives and reduced morbidity, with more rapid implementation of preventive measures which are already planned. Based on these considerations, the following section outlines the computation of the costs of the residual cholera incidences attributable to climate change which remains after preventive measures are in place. Two valuation metrics are used: cost of treatment, as a reactive adaptation measure, and a value attached to the increased mortality. Costs are calculated using constant 2006 US\$.

3.2.1 Reactive Adaptation Cost Estimation

The residual impacts are treated with reactive measures and for this purpose cost estimates of managing a cholera patient admitted in a hospital have been collected at the Ministry of Health, Tanzania. Cholera patients are not treated as outpatients, they are isolated in a special cholera ward or unit during treatment. Treatment is on average 5 days per case and includes infusions, oral rehydration salt, and antiseptics. In addition to treatment of the cholera patient, people who had contact with cholera patients are under surveillance for 5 days and given preventive treatment/therapy, and are thereby treated as outpatients. The total cost per case of managing a cholera admitted patient including treatment, cost of bed, personnel, and outpatient surveillance is 98 US\$(2006). It is assumed that all residual cases are treated with reactive measures. The total costs of reactive measures represent the residual costs of climate change impacts in terms of treatment costs. Ideally, the estimates do not represent the total value of the additional costs of climate change since loss of productivity should be included to estimate direct total cost of illness (costs of treatment, plus loss of productivity).

The estimated residual economic costs of treatment of cholera attributed to climate change are presented in Table 3. The results show that the ratio of additional costs of reactive adaptation to GDP is relatively small with a share of less than 0.1 percent for the upper bound scenario and 2 degree Celsius temperature increase. These estimates, however, only take into account morbidity, and therefore the next

section provides estimates of the economic losses from loss of lives due to cholera attributed to climate change impacts.

Table 3. Costs of projected morbidity impacts by year 2030

Scenario	Additional cases	Cost per case, US\$	Total cost of reactive measures, US\$	Total cost of reactive measures/GDP, %
Scenario C ₁ (1°C 2030)				
Lower	33,390	98	3,272,221	0.02
Upper	74,039	98	7,255,795	0.04
Scenario C ₁ (2°C 2030)				
Lower	74,460	98	7,297,054	0.04
Upper	185,837	98	18,212,046	0.09

The share of total cost of reactive measures of GDP in Tanzania by year 2030 has been calculated on the basis of GDP projections for annual GDP growth rates for Sub-Saharan Africa (Mathers and Loncar, 2005).

3.2.3 Cost of lost short term productivity

For estimating cost of cholera in Tanzania, the cost of productivity losses is calculated from wages and days out of work. For wages, a weighted average is estimated from the Integrated Labor Force Survey 2006 (URT 2007), including average wages for self employed and employees. Nearly 90 percent of the population is employed, where of 87.7 percent of this work force are self-employed, while the remaining share of the employed population are formal employees. Even people not formally employed would still contribute to economic activities and therefore a wage corresponding to an agricultural workers wage is applied as a proxy to estimate losses of the unemployed population share. Also for the cases among children it is most likely that an adult will spend time away from work to take care of the sick child and hence withdraw time from productive activities. Therefore, it is assumed in the following estimations that all cases of cholera will result in lost productivity corresponding to weighted wages from five working days, equal to the average number of days of hospitalization for a cholera case. The calculated weighted average productivity loss per case is hence 9.7 US\$.

Table 4. Lost productivity per case and for additional cholera cases attributed to climate change by year 2030 in Tanzania for each scenario respectively

Scenario	Additional cases	Productivity loss per case, US\$	Total cost of productivity losses, US\$
Scenario C ₁ (1°C 2030)			
Lower	33,390	9.7	325,264
Upper	74,039	9.7	721,241
Scenario C ₁ (2°C 2030)			
Lower	74,460	9.7	725,342
Upper	185,837	9.7	1,810,307

Table 4 present the results of productivity losses for the respective scenarios. The productivity losses account for approximately 9 percent of total cost of illness for each of the scenarios. This result

corresponds to previous estimates for malaria in South Africa which show loss of productivity to account for 8 percent of cost of illness (Turpie et al., 2002).

3.2.3 Cost of Mortality

Efficient treatment of cholera reduces risk of mortality with 80 percent (WHO, 2008b). In previous sections, the effect from treatment of cholera is included in the estimations of number deaths caused by cholera since the WHO baseline, Scenario C₀, includes a variable on impacts of technological change on health status. This variable captures the effect of knowledge and technological development on the implementation of more cost-effective health interventions, including both preventive measures (Mathers and Loncar, 2005). Therefore, in order to estimate incremental costs of mortality, number of deaths and the value of statistical life (VOSL) of 103,344 US\$ are included in the estimation of total cost of cholera attributed to climate change. This VOSL is based on the ratio of real per capita GDP, in this case for Tanzania, and adjusted to GDP in the US. By using real GDP it will take into account the purchasing power of the country, in this particular case Tanzania. The VOSL method broadly measures the individual willingness-to-pay to reduce the risk of death and have been used widely in the environmental economics literature to value mortality impacts (Markandya, 1998). The total additional cost of cholera deaths attributed to climate change can be measured from

$$Cost_d = deaths_{2030cc} * VOSL , \quad (6)$$

where $Cost_d$ is total residual cost of cholera deaths attributable to climate change. $deaths_{2030cc}$ is the additional number of deaths from cholera attributable to climate change by year 2030 as estimated in section 3.1.4 based on the econometric analysis, and lastly, VOSL is assumed equal to 103,344 US\$ as described above. There exist a number of ways to calculate the value of mortality (and morbidity estimated as DALY in previous section). Nonetheless, there is no agreement on these values, and some have argued for much higher figures than the VOSL applied above. Bosello et al. (2006) for example, take a value per life lost of 200 times per capita income, which would give a value of life around US\$1 million for South Africa. This value is almost ten times the estimate which Turpie et al. (2002) calculated for South Africa and in comparison to the VOSL applied above for Tanzania.

Table 5. Costs of projected mortality impacts by year 2030

Scenario	no. of additional deaths	US\$	VOSL,	total costs of residual deaths, US\$	total cost of residual deaths/GDP, %
Scenario C ₁ (1°C 2030)					
Lower	2,705		103,344	279,503,272	1.38
Upper	5,997		103,344	619,768,124	3.06
Scenario C ₁ (2°C 2030)					
Lower	6,031		103,344	623,292,296	3.08
Upper	15,053		103,344	1,555,617,991	7.68

The share of total cost of residual deaths of GDP in Tanzania by year 2030 has been calculated on the basis of GDP projections for annual GDP growth rates for Sub-Saharan Africa (Mathers and Loncar, 2005).

Table 5 display the results of costs attributed to deaths caused by the increasing number of cholera cases. The share of total cost of residual deaths relative to GDP is considerably larger than the burden of morbidity as estimated in previous section and evidence of a large health cost of deaths attributed to climate change impacts.

3.3.3 Total Cost of Cholera Attributed to Climate Change by 2030

The total additional economic costs of cholera attributed to climate change are calculated as the sum of total cost of treatment of residual cases, loss of productivity and the total cost of residual deaths from cholera attributed to climate change. The results are presented in Table 6.

Table 6. Total costs of cholera attributed to climate change by year 2030

Scenario	Total cost of reactive measures, US\$	Total costs of productivity loss, US\$	Total cost of residual deaths, US\$	Total cost of cholera attributed to climate change, US\$	Total cost of cholera attributed to climate change/GDP, %
Scenario C ₁ (1°C 2030)					
Lower	3,272,221	325,264	279,503,272	283,100,757	1.40
Upper	7,255,795	721,241	619,768,124	627,745,160	3.10
Scenario C ₁ (2°C 2030)					
Lower	7,297,054	725,342	623,292,296	631,314,692	3.12
Upper	18,212,046	1,810,307	1,555,617,991	1,575,640,344	7.78

The share of total cost of GDP in Tanzania by year 2030 has been calculated on the basis of GDP projections for annual GDP growth rates for Sub-Saharan Africa (Mathers and Loncar, 2005).

The costs of cholera attributed to climate change ranges between 1.4 and 7.8 percent of GDP by 2030. The upper bound for the 1 degree Celsius scenario and the lower bound estimate for the 2 degrees Celsius scenario lie around 3.1 percent of GDP. This is a considerable share of GDP, bearing in mind that the full health costs of climate change would be much larger if taking into account other health variables affected by climate change such as other water-borne diseases besides cholera (e.g. diarrhea, typhoid), malnutrition, food-borne (e.g. Salmonella) and vector-borne diseases (e.g. malaria, dengue).

In order to compare these costs with the costs of prevention we look at the number of DALYs avoided as an estimate of the cost per DALY avoided is available in the literature (Clasen et al, 2007). Table 7 displays the cost ranges of water quality interventions for preventing cholera. These estimates are evidence of considerable benefits of preventive measures in comparison to the total costs of cholera attributed to climate change in Tanzania in year 2030 as reflected in Table 6.

Table 7. Costs of preventive adaptation measures in terms of cost per DALY averted and the total cost estimates of averted DALY's attributed to climate change impacts in Tanzania by year 2030

Scenario	Additional number of DALY's	Cost per DALY averted, US\$	Total cost range to avoided DALY, US\$
Scenario C ₁ (1°C 2030)			
Lower	127,584	59 -137	7,544,042 - 17,507,076
Upper	282,899	59 -137	16,727,818 - 38,819,401
Scenario C ₁ (2°C 2030)			
Lower	284,507	59 -137	16,822,899 - 39,040,051
Upper	710,070	59 -137	41,986,439 - 97,435,805

The cost range per DALY averted is based on Clasen et al. (2007) where a cost of 59 US\$ is for household chlorination and 137 US\$ is for improvements of the water source such as dug wells, boreholes and stand posts.

4. Discussion

This paper is the first study to link cholera incidences to environmental and socioeconomic factors and using it for predicting climate change impacts to cholera. Climate variables have a significant impact on the occurrence of cholera and will significantly affect the burden of cholera attributable to climate change. The results presented in this paper are in accordance to what would be expected given the previous evidence on linkages between environmental risk factors and health indicators, including diarrheal diseases. Other studies have analysed the relationship between cholera and environmental factors (Fernández et al., 2009) and linkages between incidence of diarrheal diseases as an aggregate measure and environmental and socio-economic factors (Singh et al., 2001; Koelle et al., 2005; Checkley et al., 2000; Wang et al., 2009). For a waterborne disease, the figures presented in this paper look quite high in comparison to the 8 to 16 percent increase in the initial risk of diarrheal diseases by year 2030, as predicted by WHO (2008a) for Sub-Saharan Africa. However, Wang et al. (2009) predict an increase in diarrheal incidences in the range of 0.6 percentage point for a 1 degree Celsius increase in temperatures for South Arica. The estimates presented in this paper predict an increase of 0.05 – 0.1 percentage point for a 1 degree Celsius increase in temperatures for Tanzania.

The cost estimates used for reactive adaptation are based on unpublished data from Ministry of Health in Tanzania. These costs are considerably higher than the costs of treating diarrhea since diarrheal patients can be treated as outpatients while treatment of cholera has to include hospitalization for an average of 5 days per case and also include cost of surveillance of other people than the patient. In Zambia, inpatient average costs for diarrhea are estimated as 78 US\$(2006) per bed day (Chola and Robberstad, 2009), while for Tanzania, inpatient costs are estimated in the range of 3.40 – 11.86 US\$(2006) per day (Flessa, 1998). The latter figures correspond well to the cost figures provided by

Ministry of Health in Tanzania on 98 US\$(2006) for 5 days of hospitalization. For South Africa, the additional treatment cost of diarrheal cases attributed to climate change by year 2020 is estimated to be equivalent to a 0.2 – 0.52 percent share of GDP (Wang et al. 2009). On this basis, the reactive costs of additional cases of cholera in Tanzania by year 2030 in the range of 0.02 – 0.09 percent share of GDP do not seem unreasonably high.

The results presented in this study have two main limitations. Firstly, the econometric data analysis is based on aggregate monthly and annual measures, and therefore it is likely that with more time-specific data available on health and climate variables, the result could show even stronger impacts. The impacts from climate variability on burden of disease from cholera are complex and dependent on a number of risk factors from local socio-environmental conditions. Nevertheless, the results still provide robust evidence on the implications of climate variability to cholera and to the health sector in terms of costs of additional cases and related deaths. The second limitation is related to the projected number of cases and deaths for the baseline, which are estimated from WHO Global Burden of Disease study (WHO, 2008a). This projection includes projections for diarrheal diseases as an aggregate measure for Sub-Saharan Africa by 2030. The WHO projections are not released at country levels but, nonetheless, the regional projections should provide a reasonable guide to future trends for countries in the respective regions. Based on this, the share of cholera deaths from diarrheal deaths is calculated using Tanzania average share of deaths caused by cholera in respect to diarrheal deaths from WHO epidemiological reports 2003-2009 (WHO, 2003-09).

The implications of the results presented in this paper for future studies suggest that climate change will cause large additional economic burdens to societies and to households. Consequently, it is vital to quantify the burden of disease attributable to climate change at national and local levels opposed to regional levels since the human health vulnerability to climate change, in terms of exposure (environmental variables) and capacity to cope (socioeconomic variables), may vary considerably between time and place. Therefore more and improved projections of future risks are necessary for local (national) decision making in addition to further efforts to refine national costs of preventive and reactive adaptation measures in the health sector.

5. Concluding Remarks

The association of temperatures and cholera cases and deaths remains significant also when controlling for socioeconomic factors. The risk ratio showed to increase with rising temperatures, while the case fatality rate proves to be more related to socioeconomic health conditions than to climate variables. Integrating both climate variables and socioeconomic variables in one model confirm that human health conditions are influenced by many factors and cannot be addressed in isolation. Increase in income and access to safe water proved to reduce the cholera case fatality rate. The results of these effects in relation to the impacts of climate change suggest that it would turn out very beneficial to improve socioeconomic indicators, including access to water and sanitation, even more quickly than originally planned. There is unquestionably a wide array of other benefits for improving performance on these indicators, since they influence on a number of other development objectives such as nutrition and education. Also, the estimates of costs of preventive measures evidence of considerable benefits of water quality improvements programmes such as household chlorination in comparison to the costs of reactive adaptation measures.

The estimations, based on assumptions of climate change projections, suggest that the cholera health cost of increased temperatures of 1 to 2 degree Celsius by year 2030 will be in the range of 0.02 to 0.09 percent of GDP for treatment cost alone (cost of reactive adaptation), while total additional cost attributed to climate change, including the value of loss of lives, would likely be around 3.1 percent, but possibly as much as 7.78 percent of GDP by 2030 for the upper bound. The magnitude of these cost estimates of additional cases of illness resulting from climate change are substantial, and considerably higher than the current budgets allocated for diarrheal diseases in most developing countries. Thus budgetary increases will be needed if treatment is to be provided to deal with the additional cases which are not avoided through preventive adaptation measures.

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Annex 1: Econometric results

A1) Poisson model – monthly data: cholera cases

```

Poisson regression                                Number of obs =      84
                                                Wald chi2(2) =     17.18
                                                Prob > chi2 =     0.0002
Log pseudolikelihood = -22523.21              Pseudo R2 =     0.2418

```

```

-----+-----
                |               Robust
chocases |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----+-----
maxtemp |   .4146464   .1010562     4.10   0.000     .21658   .6127129
trend   |   .0081052   .0059336     1.37   0.172    -.0035244 .0197349
_cons   |  -23.54482   3.030775    -7.77   0.000    -29.48503 -17.60461
population | (exposure)

```

```

Poisson regression                                Number of obs =      84
                                                Wald chi2(2) =     17.18
                                                Prob > chi2 =     0.0002
Log pseudolikelihood = -22523.21              Pseudo R2 =     0.2418

```

```

-----+-----
                |               Robust
chocases |      IRR   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----+-----
maxtemp |   1.513835   .1529824     4.10   0.000     1.241822   1.845431
trend   |   1.008138   .0059819     1.37   0.172     .9964818   1.019931
population | (exposure)

```

A2) Poisson model – annual data: cholera cases

```

Poisson regression                                Number of obs =      28

```

Wald chi2(3) = 13124.16
 Prob > chi2 = 0.0000
 Log pseudolikelihood = -538.40245

```
-----+-----
```

	Robust					
chodeaths	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
maxtemp	.2093469	.0057727	36.27	0.000	.1980327	.2206611
realgdpcap	-.0017584	.0002964	-5.93	0.000	-.0023393	-.0011776
chocases	.0001334	5.83e-06	22.86	0.000	.000122	.0001448

```
-----+-----
```

Poisson regression
 Number of obs = 28
 Wald chi2(3) = 13124.16
 Prob > chi2 = 0.0000
 Log pseudolikelihood = -538.40245

```
-----+-----
```

	Robust					
chodeaths	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
maxtemp	1.232873	.0071169	36.27	0.000	1.219002	1.246901
realgdpcap	.9982431	.0002958	-5.93	0.000	.9976635	.9988231
chocases	1.000133	5.83e-06	22.86	0.000	1.000122	1.000145

```
-----+-----
```

A3) Poisson model – annual data (panel of regions): cholera cases

Random-effects Poisson regression
 Number of obs = 119
 Group variable: geocode
 Number of groups = 17
 Random effects u_i ~ Gamma
 Obs per group: min = 7
 avg = 7.0
 max = 7

alpha | 1.581317 .46092 .8931246 2.799793

 Likelihood-ratio test of alpha=0: chibar2(01) = 2.5e+04 Prob>=chibar2 = 0.000

A4) Linear (OLS) models – annual data: cholera deaths

Linear regression Number of obs = 28
F(2, 25) = 12.89
Prob > F = 0.0001
R-squared = 0.8099
Root MSE = 192.98

	Robust					
chodeaths	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
chocases	.0815743	.0175598	4.65	0.000	.0454093	.1177394
realgdpcap	-.7438819	.204264	-3.64	0.001	-1.164572	-.3231923
_cons	381.4173	91.52764	4.17	0.000	192.9126	569.922

Linear regression Number of obs = 15
F(2, 12) = 9.57
Prob > F = 0.0033
R-squared = 0.8295
Root MSE = 234.4

	Robust					
chodeaths	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
chocases	.0779042	.0193398	4.03	0.002	.0357665	.1200418

watercover	-4925.379	1516.12	-3.25	0.007	-8228.72	-1622.038
_cons	2628.87	790.597	3.33	0.006	906.307	4351.433

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Paper 4



**‘Development and Climate Change: A Mainstreaming Approach for Assessing Economic, Social, and Environmental Impacts of Adaptation Measures’,
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Development and Climate Change: A Mainstreaming Approach for Assessing Economic, Social, and Environmental Impacts of Adaptation Measures

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Abstract The paper introduces the so-called climate change mainstreaming approach, where vulnerability and adaptation measures are assessed in the context of general development policy objectives. The approach is based on the application of a limited set of indicators. These indicators are selected as representatives of focal development policy objectives, and a stepwise approach for addressing climate change impacts, development linkages, and the economic, social and environmental dimensions related to vulnerability and adaptation are introduced. Within this context it is illustrated using three case studies how development policy indicators in practice can be used to assess climate change impacts and adaptation measures based on three case studies, namely a road project in flood prone areas of Mozambique, rainwater harvesting in the agricultural sector in Tanzania and malaria protection in Tanzania. The conclusions of the paper confirm that climate risks can be reduced at relatively low costs, but the uncertainty is still remaining about some of the wider development impacts of implementing climate change adaptation measures.

Keywords Climate change · Mainstreaming · Sustainable development

Introduction

Climate change is a global environmental problem, and international studies have predominantly addressed climate change from an environmental policy perspective. However, emerging literature recognises that climate change variability, extreme events and structural changes have major impacts on economic, social and human living conditions as well as on natural systems. This implies, in developing countries, that key goals related to poverty reduction, water, food, energy, education and health are critically influenced by climate change, and that adaptation measures therefore should be tackled in the context of development policies.

The strong relationship between climate change and development is also recognised by IPCC in its Fourth Assessment report by stating that “The distribution of impacts and vulnerabilities is still considered to be uneven, and low-latitudinal less-developed areas are generally at greatest risk due to both higher sensitivity and lower adaptive capacity; but there is new evidence that vulnerability to climate change is also highly variable within countries, including the developed countries” (IPCC 2007, p. 781).

Existing efforts on climate change and development linkages include activities by the International Institute for Environment and Development (IIED), which has worked on mainstreaming climate change and on disaster risk reduction (Yamin and Huq 2005; Huq and others 2006), and the World Resources Institute which, in a recent methodological case study analysis, has addressed how adaptation can be framed in the context of development

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(McGray and others 2007). OECD is similarly in a process of developing guidelines for how development assistance can take climate change into consideration, and this work has been supported by several technical adaptation studies (Agrawal 2005).

Recognising the importance of linking development and climate change, the so-called mainstreaming approach aims at evaluating climate change policies in the context of general development goals. The objective of this paper is to introduce how a mainstreaming approach can be operationalised, and to demonstrate how it can be used in relation to case studies in Mozambique and Tanzania.

It is important to recognise that applying a mainstreaming approach opens a new set of issues on how to compare the use of scarce development funds for climate change adaptation with alternative uses. In many cases climate change adaptation can go hand in hand with other development activities in such a way that the activities jointly support the same goals. In other cases, adding an element of adaptation to development policies imposes significant costs that can imply delaying out other development investments from which a discussion about different priorities can emerge. In practice, however, it can be expected that some part of the additional costs from including climate change adaptation can be paid by international funds or bilateral donors, in which case there is no national conflict between spending resources on development programmes and climate change adaptation.

There are several implications of applying a mainstreaming approach to the evaluation of climate change adaptation policies:

- Climate change is addressed as a development problem and aspects like human welfare and its various social and human dimensions are linked to environmental issues.
- The issue moves into the domain of multiple sectors including agriculture, water, health, energy and infrastructure.
- The current impacts of climate extremes and disasters and their links to development are the starting points for assessing future climate change impacts.
- There is a need for linking climate change impact data and development statistics, which, given uncertainties and data limitations, complicates adaptation studies.

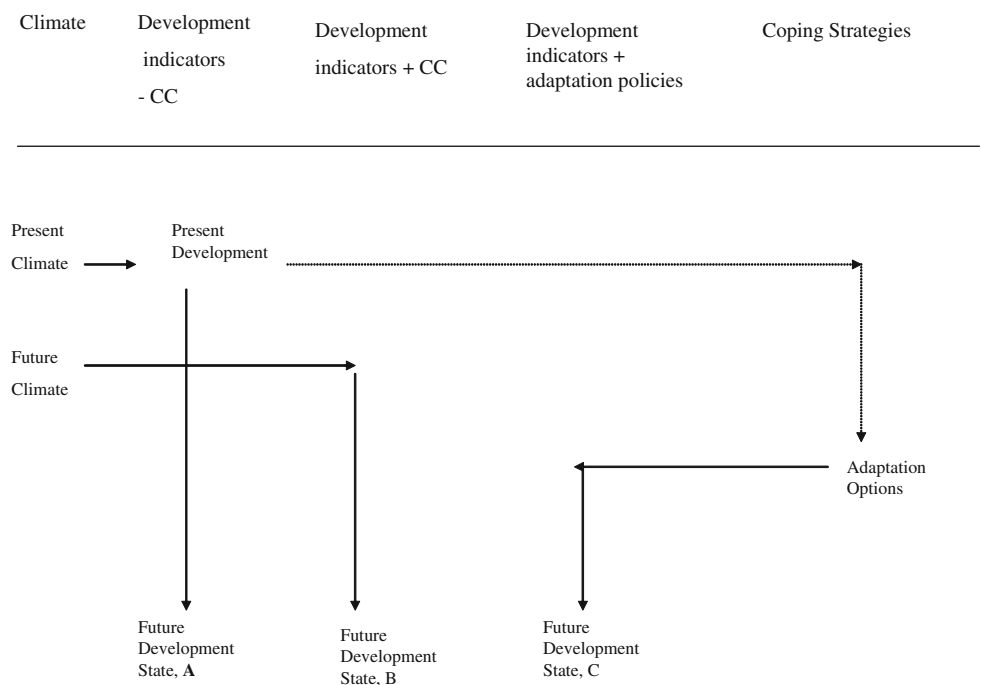
The next section presents an analytical framework that can be used to assess climate change in a context of development analyses.

Analytical Framework

The idea of the mainstreaming approach is to assess climate change impacts and vulnerabilities in the context of development. Figure 1 below illustrates a structure that can be used to assess the relationship between development, climate change and adaptation options.

The figure is structured in five columns. Starting from the left the first column represents the Climate System that can be characterised by a set of climate variables such as temperature, precipitation and humidity (x_1, \dots, x_n). The second, third and fourth columns illustrate development

Fig. 1 Structure for assessing development, climate change, and adaptation relationships



without climate change (column 2), with climate change (column 3) and with both climate change and adaptation policies (column 3). Development in these three columns can be characterised by a set of variables (y_1, \dots, y_n) that can be understood as focal indicators of various economic, social and environmental development targets considered to reflect key priorities. Finally, column 4 represents adaptation strategies that can be characterised by a set of variables (z_1, \dots, z_n).

It is important to recognise that all the elements and analytical steps included in the figure are surrounded by significant uncertainties and data limitations. This includes establishing climate information at a detailed regional level to link climate data and socio-economic factors.

The vertical dimension of the diagram represents the time dimension. Starting at the top left corner of the diagram, the starting point assesses how the present climate influences the development today. Similarly, future development stages are influenced by the climate and are termed Development State **A** if the climate is unchanged, and Development State **B** if the climate is changed. Studies of climate change in the context of development (mainstreaming) include an assessment of the links between the climate and development objectives at present and in the future. This assessment can suggest implementation of adaptation options and results in the achievement of a new Development State **C**.

It should be recognised that it is a very demanding task to establish quantitative data for assessment of the relationship between climate and specific development dimensions (or development goals) even if this is done at a detailed level for specific activities, like farming at provincial level. The complexities arrive from several factors including limited availability of long time series of climate data that can be linked to farming output and incomplete understandings of the many factors that play together in production functions in agriculture including climatic factors, land, labour, machinery, seeds, irrigation and education.

In a more simple way it can be said that the aim of mainstreaming assessments is to ensure that current, as well as future development policies, are well adapted to the climate and this can imply that some adaptation options are recommended. This way the mainstreaming approach aims at assessing the relationship between the climate and development in general, without giving specific consideration to distinguishing anthropogenic climate change impacts and vulnerabilities from climate vulnerability of development policies per se. This is different from approaches such as those applied by GEF funding, where the assessment of incremental costs of adaptation to anthropogenic climate change is a focal point.

The fact that many economic activities at present are not well adapted to climatic conditions is complicating.

Examples are rain feed agriculture in dry areas where irrigation facilities are not available, or livelihoods in low lying areas that suffer from flooding. In such cases mainstreaming climate assessment can reveal that a future development state like **C** (Fig. 1) can be better off in terms of development indicators than a future development state like **A** which, by definition, assumes that no climate change is occurring. This can be the case when it is assumed that some current maladaptations to the current climate, as well as future negative climate change impacts, are overcome in state **E** and adaptation policies in such a case sometimes can render development benefits larger than the costs of implementing the options.

Based on the structure given in Fig. 1, a stepwise mainstreaming approach for assessing adaptation can include the following analytical elements.

Element 1: Climate Conditions, Variability and Future Changes

The initial basis for the assessment is to establish data about the present climate, its variability and the potential changes over time. Time and geographical resolution should be rather detailed in order to facilitate the use in relation to sectoral and local assessments.

Element 2: Selection of Development Indicators

The next step is to select development indicators that reflect key economic, social and environmental policy objectives and climate sensitivities.

Element 3: Assessing the Relationship between Climate Variables and Development Indicators related to Specific Activities

Element 1 and *Element 2* can then be combined in order to understand the sensitivity of development policies to the climate. Preferably the links should be based on statistical data and should provide a basis for projecting the impacts of future climate changes.

Element 4: Adaptation Options

Finally the assessment can identify adaptation options that can be used to make current and future development states better adapted to climate change, in order to measure the costs and development impacts of implementing these options.

The stepwise analytical approach is applied to the assessment of case examples of climate change vulnerability and adaptation from Mozambique and Tanzania, in order to shed more light on the individual elements.

Definition of Climate, Development and Policy Variables

Integrated climate change and development assessments can address a number of policy issues related to a short list of well-defined policy variables, which can be used to point to key development and climate issues as introduced in Fig. 1 above. The major focus of mainstreaming studies is to meet specific development objectives and therefore the climate impacts should be assessed in relation to how they influence key development policy goals. The very pragmatic approach recommended here suggests selecting a limited set of indicators considered to represent key areas where climate–development linkages can be addressed. These areas will depend on sectoral focus but can include economic areas in terms of costs, investments and employment; social areas in terms of income to poor families, education and health; and environmental areas in terms of different pollutants. Table 1 gives an overview of how the economic, social and environmental areas can be measured.

In practice it will not be possible to cover all the aspects included in Table 1, hence a few areas, particularly relevant for the focal study area, must be selected. In an agricultural study from Bangladesh (Mirza 2002) it is seen how the different elements in the mainstreaming approach can be used. The study assessed possible future changes in the magnitude and return periods of floods and related crop damages as a consequence of climate change under various warming scenarios. Historical data from 1965 to 1992 was applied to estimate future flood occurrence for three large rivers in Bangladesh and climate scenarios were developed in order to model climate conditions, variability and

changes (see *Element 1 above*). The analysis demonstrated significant changes in the mean annual peak discharges of the rivers for various warming scenarios. Crop damages were chosen as development indicators (*Element 2*), and the relationship between combined peak discharges of the three rivers and amount of crop damage was established (*Element 3*), assuming crop damage during a monsoon to be a function of flood volume. The results were subsequently used to estimate flood impacts on crop yields in the affected areas, employment in the agricultural sector and agricultural GDP contribution. Finally capacity building in the agricultural sector was mentioned as an adaptation option (*Element 4*) to reduce crop damages, but no further detailed analysis on this measure was conducted.

Mainstreaming Studies for Case Studies in Mozambique and Tanzania

The climate change mainstreaming approach is illustrated based on three case studies for Mozambique and Tanzania and the previously introduced stepwise analytical approach is used to assess climate change, development impacts and potential adaptation measures. Due to data limitations the analyses are indicative of potential impacts and adaptation measures rather than accurate information about all relevant aspects and it has in practice primarily been possible to include a limited number of indicators of the direct costs and benefits of implementing specific measures. The limitations of these economic parameters will be highlighted in relation to the different case examples and this will be followed up by a discussion about what the implication of addressing a wider range of development indicators could have been. The case examples are infrastructure planning in Mozambique, rainwater harvesting in Tanzania and Malaria protection in Tanzania. An overview of the examples is given in Table 2.

The focus of the Mozambique case study is on how roads can be made flooding proof and the additional resources required relative to the value of improved market access. The cases examined for Tanzania are rainwater harvesting for management of irrigation water in order to cope with expected increased precipitation variability with climate change, and malaria treatment to cope with current and expected increasing future risks with higher temperatures in the highlands.

Example 1: Infrastructure Planning in Mozambique

The Limpopo Basin in southern Mozambique is an area extremely at risk to flooding. This was already seen in the 2000 flooding where more than 500 people died, 200,000 people were forced into refugee camps and impacts on

Table 1 Examples of development policy dimensions and measurement standards that can be applied to the assessment of development–climate linkages

Impacts areas	Indicators	Measurement standards
Economic	Costs	Cost measures
	Employment	Economic surplus/profit
	Investments	Capital requirements Jobs
Social	Income	Income generation and distribution
	Education	Time available for education
	Health	Number of people with different diseases
Environmental	Climate change	GHG emissions
	Local pollution	Local pollutants Ecosystem degradation

Table 2 Overview of climate change and development impacts of case studies in Mozambique and Tanzania

Example	Climate change impacts	Development impacts considered	Adaptation options
Infrastructure planning	Highways in Mozambique are expected to be damaged by increasing magnitude and intensity of floods. The damages will increase maintenance costs and can cause temporary disruptions	<ul style="list-style-type: none"> • Maintenance costs • Impacts of disrupted market access at local and regional level 	<ul style="list-style-type: none"> • Road drainage systems • Stronger foundation and bridges • Alternative routes
Rainwater harvesting in agriculture	Climate change is expected to influence the magnitude and time distribution of precipitation in Tanzania, and agriculture therefore can be increasingly dependent on irrigation	<ul style="list-style-type: none"> • Crop yields • Employment • Income 	<ul style="list-style-type: none"> • Increased water storage capacity for irrigation purpose
Malaria prevention	Increased temperatures and changed precipitation patterns that is expected to increase number of malaria incidences	<ul style="list-style-type: none"> • Treatment costs • “Sickness” • Mortality 	<ul style="list-style-type: none"> • Malaria bed nets and information campaigns

infrastructure caused serious damages to the roads and bridges, preventing normal traffic along the main road for more than 6 months (INGC 2003). The basin is the second largest in Mozambique and its dams have very little storage capacity for regulating water flow into the lowlands, meaning that downstream areas experience sudden increases in water levels and currents during periods of heavy rains. The flooding is difficult to regulate since it depends on cross border river systems. In this way the lowlands are facing flooding risks and the risks are further accelerated by climate change impacts. This example focuses on road infrastructure and resistance of roads to flooding in the southern part of Limpopo which is highly populated. The stepwise mainstreaming approach is applied as follows:

Element 1: Climate Conditions, Variability and Future Changes Climate projections and regional hydrological models for southern Africa, including Mozambique, indicate that climate change can lead to significant changes in timing and magnitude of water run-off which can consequently increase the frequency and scale of flooding. Recent climate statistics show that the average total regional precipitation has decreased for southern Africa, including Mozambique, but there has been a statistically significant increase in the regionally averaged daily precipitation intensity for the period 1961–2000 (New and others 2006). Flooding in the Limpopo Basin is often caused by heavy rainfall in South Africa, Zimbabwe and Botswana (Vaz 2000). The observed trends of increased rainfall intensity can therefore be expected in the future to lead to more floods in the Limpopo Basin. Results based on the IPCC’s SRES emission scenarios for river run-off using the HadCM3 climate models indicate a significant increase in run-off for 2050 (Arnell 2003, 2004).

Element 2: Selection of Development Indicators The expected increase in magnitude and intensity of floods will affect rural livelihoods, health, agriculture and roads in the

Limpopo Basin. Due to data availability the current case study is only addressing direct impacts on roads, but a more qualitative description of other impact areas are subsequently given. In addition to reconstruction and maintenance costs, the flooding will also have indirect costs related to disrupted market access when the roads are out of function.

Element 3: Assessing the Relationship between Climate Variables and Development Indicators related to Specific Activities Disrupted market access in flooding periods has shown to imply limited food supplies to and from markets as well as price increases and this becomes more pertinent when the demand in flooding periods increases due to loss of crops and livestock. For example, the flood in Mozambique in 2000 entailed a 70% price increase for maize (INGC 2003).

A number of broader development impacts of the Limpopo flooding in 2000 are shown in Table 3 and these numbers subsequently are used to discuss the costs of flooding events as such.

The 2000 flooding in Limpopo displaced almost 300,000 people and included 78 villages as seen in Table 3. The damage on houses resulted in reconstruction costs of over 40 million US\$ and 4 million US\$ for schools. During the 2000 flood the affected areas experienced food price increases of up to 70% for a duration of 2–3 months, where after prices decreased to normal levels (INGC 2003) with consequences for consumption expenditures. Based on the assumption that the average monthly consumption per person in the area is estimated to be 229 US\$ (GoM 2001), a 70% price increase would result in increasing expenditures for consumption of about 390 US\$ per person during the flooding period. People may not be able to economically respond to the higher costs of consumption and therefore they may adjust to lower consumption levels.

Step 4 Adaptation Options The adaptation options considered in this section focuses on the roads as an example

Table 3 Flood impacts in the Limpopo Basin, year 2000

Indicator	Unit	Total cost of damage per unit, US\$	Total cost of damage Mill US\$	Cost of reconstruction per unit, US\$	Total cost of reconstruction Mill US\$
Number of people displaced	295,500				
Number of villages displaced	78				
Number of houses damaged	47,000	580	27.0	872	41.0
Number of schools damaged	60	37,400	2.2	37,400	4.0

Data computed from INGC (2003) and World Bank (2000)

of a key impact area and does not cover all impacts on houses, villages and other assets. Potential adaptation measures against flooding include construction of roads with drainage systems, increased road levels, alternative routes, stronger foundation and bridges. These options can be integrated in construction and rehabilitation plans based on risk assessments of future climate variability and change.

The cost considerations of adaptation to climate change of road infrastructure in the Limpopo Basin is further based on data from a rehabilitation and maintenance project for a 20 km road in Limpopo (World Bank 2000, 2001) that is planned to be implemented over 10 years. This project is used as a baseline case. The project assumes design profiles to include future higher traffic levels and greater resistance to flood damages based on historical flooding trends, and it is expected that this construction will reduce losses from flooding by 50%. In addition the baseline assumes flood loss exposure to be reduced by 50%. This reduction is due to an integrated minor drainage systems adjusted to accommodate a 1-in-20 year flood and profiles for major structures, e.g. bridges, to accommodate a 1-in-40 years flood.

Future climate change has not been taken into consideration in this project. Taking this into consideration would imply that an assessment of the construction and maintenance costs with and without climate change is conducted. The magnitude of such costs can be understood based on a study from the Federate States of Micronesia (ADB 2005)

that calculated the construction costs of a road with and without climate change adaptation options integrated. The upfront costs of the road increase if climate change adaptation is considered but will be offset by lower maintenance costs and the net costs consequently will be lower after 15 years. Over 50 years total construction, maintenance and repair costs of the road without climate change adaptation measures showed to be 56.5% above the costs for a road with adaptation measures included. Table 4 illustrates the costs of two road scenarios with and without climate change adaptation measures which are calculated based on assumptions on economic estimates from the Micronesia study by ADB (2005).

In addition to the net cost savings of the road project with adaptation, the improved road will also facilitate easier access for emergency and relief in flooding periods and will reduce periods with inadequate market access. Furthermore more rapid emergency response will potentially decrease the number of incidences of disease. The 2000 flood showed that where roads were more rapidly reconstructed, the areas stabilised and returned to normal conditions faster compared to areas which were isolated for longer periods.

Example 2: Rainwater Harvesting in Tanzania

Climate change is predicted to extend the period between rainfalls in Tanzania (Hulme and others 2001). During dry seasons, dry spells with almost no rain are expected to

Table 4 Costs of road construction with and without mainstreaming of climate change adaptation measures

	Costs per km (US\$)	
	Without adaptation measures	With adaptation measures
Cost of construction		
Road surface	190,000	190,000
Drainage work	96,970	174,393
Total costs of construction	287,121	364,545
Incremental cost		77,424
Total cost of construction, maintenance, and repair costs	1,182,273	755,455
Net benefit of mainstreaming adaptation measures		426,819

become more common while the number of spells with high intensity precipitation seems to increase during the rainy season. Crop yields will most likely decrease if water is not stored during the rainy season even without climate change. Taking climate change into consideration, water availability will be even scarcer during the dry season (which is longer and dryer) and the demand for water storage is extended compared to a situation without climate change. Potential adaptation options include increased water storage capacity and improved water management. If such adaptation measures are integrated into the planning process of the agricultural season, improved water management can alleviate the effect from decreased rainfall during the growing season.

The economic assumptions in this example are based on a case study by Kadigi (2003) about water availability for irrigation of rice paddies and the impacts on crop yields, in Dodoma region, Tanzania. The Dodoma climate is characterised by a long dry season lasting between late April and early December and a short single rain season occurring during the remaining months. The average rainfall for the Dodoma Region is 574 mm and about 85% of this falls in the months between December and April (Tanzania Meteorological Agency 2006). Rainfall is rather unpredictable in frequency and amount and climate change is expected to increase this uncertainty. The unreliable rainfall imposes a pattern of risk aversion in agriculture and is a serious constraint on present efforts to improve crop yields. As it can be seen from Fig. 2 the annual variability has been particularly large in 2001 and 2002.

The following stepwise approach is considering alternative water availability scenarios under present conditions and these alternatives are used as a basis for assessing the impacts of water scarcity in dry seasons under future climate variability and change. The water availability data in this study corresponds to less rainfall variability than is seen under climate change. Scaling up this data as done in the current example would most likely give a relatively low estimate of the impacts.

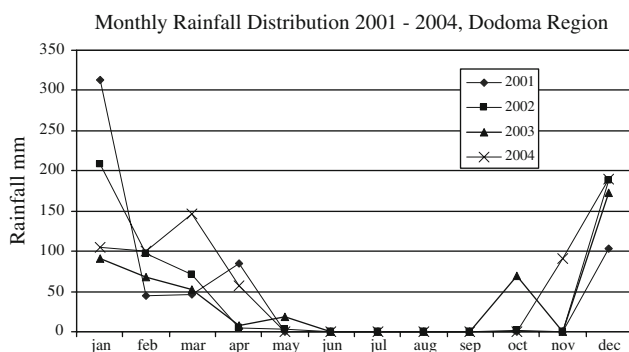


Fig. 2 Monthly rainfalls from 2001 to 2004 in the Dodoma Region, Tanzania (Tanzania Meteorological Agency 2006)

Element 1: Climate Conditions, Variability and Future Changes Precipitation is predicted to increase with 5–30% during the rainy season and decrease with 5–10% during dry months for year 2020 in Tanzania and especially the interior part of the country will experience temperature increases and longer dry periods (Hulme and others 2001 and Clark and others 2003).

Element 2: Selection of Development Indicators Changes in precipitation will influence water availability and will extend the demand for larger water storage if precipitation is concentrated over a shorter period. This will influence crop yield and this again influences other indicators such as income, agricultural employment and nutritional status in the household.

Element 3: Assessing the Relationship between Climate Variables and Development Indicators related to Specific Activities Water shortage limits the quantity and variety of crops and also has a negative influence on the possibilities for enhanced crop or livestock production in relation to emerging markets. Water shortage, therefore, presents a key barrier to poverty reduction in poor rural areas. Crop yields generally depend on temperature and precipitation patterns. The relationships between temperatures, precipitation patterns and crop yields have been established in a number of studies, e.g. for the US, but the relationship is very context specific both in terms of crops, geographical location and specific climate conditions (Rosenzweig and others 2001; Mohamed and others 2002; Meertens and others 1999) and there is therefore some uncertainty about the relationship in Tanzania. More frequent droughts and decreased water availability during dry months will shorten the growing season and reduce crop yields. Nonetheless, few studies have been done for Tanzania and the existing studies do not integrate climate change considerations or take into account increased variability in precipitation patterns (Kadigi and others 2004; Senkondo and others 2004; Hatibu and others 2006). The existing studies follow the historical trends in rainfall variability and do not consider or prepare for increased rainfall variability or demand for extended water storage capacity.

Element 4: Adaptation Options Potential adaptation measures to changes in rainfall patterns for crops include rainwater storage for irrigation, adjustment of planting dates, changes in fertilisation, introduction of new crop varieties and location, application of conservation tillage and reduced utilisation of marginal lands.

The current example focuses on expansion of water storage capacity based on rainwater harvesting for paddy rice production as the adaptation option which, can be implemented by farmers with low cost. Paddy rice cannot be grown without irrigation and rainwater harvesting systems are therefore already applied today. However, up-scaling efforts are needed in order to cease the effect from

Table 5 Historical and expected future rainfall in Dodoma region

	Rainfall in millimetres, historical trend (1974–2004)	Rainfall in millimetres, expected future trend (2020)
Total average rainfall, rain season	488	586
Total average rainfall, dry season	86	77
Total rainfall	574	663

Based on Tanzania Meteorological Agency (2006)

longer to dryer periods between rains. The example assesses the costs and benefits of an extended rainwater harvesting scheme. This is compared to a baseline case where historical rainfall trends are assumed. In both climate scenarios rainfall in Dodoma is assumed to decrease by 10% during the dry season and increase with 20% during the rainy season. Total rainfall is thereby assumed to increase, but the dry period has become dryer and the rain season is more wet. This is illustrated in Table 5. In addition the rainwater harvesting schemes are assumed to last beyond year 2020. Table 5 illustrates that total amount of rainfall is likely to increase but there will be larger variation between the rainfall in the dry and the wet season.

The expanded water storage capacity is obtained from an extension of an existing excavated bounded basin, a method of run-off utilization, management and storage of water for paddy rice production. The expansion is constructed by digging to a depth of 0.2–0.5 m and the scooped soil is used to build a bund around the field perimeter (Lazaro and others 2000). Construction costs are amortised over a life time period of 10 years assuming 10% annual maintenance cost. The only construction inputs are land and labour. Cost of land is assumed to be zero while labour is assumed to be provided by family members having low opportunity costs, especially if the work is carried out during slack season. The cost of hired labour used in peak seasons for sowing and harvesting is valued based on opportunity cost of labour used in a study of rainwater harvesting in Tanzania (Senkondo and others 2004).

In order to compare the situations with and without adaptation, a gross margin analysis is carried out to assess costs and benefits of the intervention. Precipitation patterns and temperatures are assumed to be equal in the two situations. The results are depicted in Tables 6 and 7.

A comparison of the cost-benefit analysis with and without adaptation options (Tables 6 and 7) shows that there is an increase in the average gross margins from US\$ 94 per hectare to US\$ 221 in the first year with adaptation and this gain increases in the subsequent years since all the construction costs fall in year 1 (see also Table 8). The

extended rainwater harvesting system implies a very large increase in the yield from 352 kg/ha without adaptation to 586 kg/ha with adaptation. The net present value (NPV) for the total result of the adaptation investment is calculated from the net benefits of adaptation and is shown in Table 8.

The analysis clearly demonstrates that the returns to the investment, in extended water storage capacity under climate change exceed the returns of the baseline situation with no climate adaptation measures. Hence the example shows that a relatively simple adaptation intervention, such as rainwater harvesting, is beneficial in terms of economic return as well as of increased food security in the dry seasons. Furthermore, this adaptation option has many positive side-effects in terms of improved health conditions from decreased malnutrition, which is also a key vulnerability factor in relation to Malaria.

Example 3: Malaria prevention in Tanzania

Malaria is a key contributor to mortality and morbidity in Tanzania and as much as 93% of the population in Tanzania is at risk of malaria (WHO 2003a). People at risk live in areas with relatively stable malaria transmission or in areas where malaria risk is seasonal and less predictable because of either altitude or rainfall patterns. In areas with seasonal risk of malaria, the risk is likely to change due to changes in rainfall and temperatures imposed by climate change and are expected to become more widespread throughout the year. The following case example will focus on malaria prevention as well as vulnerabilities and adaptation measures related to malaria using the previously introduced stepwise approach.

Element 1: Climate Conditions, Variability and Future Changes Referring to Example 2, the East African highlands are highly susceptible to predicted climate variability and changes. These include expected increases in precipitation by year 2020 with 5–30% during rainy season and decreases with 5–10% during the dry months and prolonged dry seasons due to increased climate variability and change (Hulme and others 2001; Clark and others 2003). Daily temperatures are predicted to increase by an average of 0.5°C per decade through the 20th century (Hulme and others 2001).

Element 2: Selection of Development Indicators The development indicators applied in this case example are the number of malaria incidences and mortality. There are also a number of other impacts of malaria, many other health issues are indirectly linked to malaria and malaria indices have huge welfare costs for individuals and causes loss of income. Repeated malaria infections make young children more susceptible to other common childhood diseases, such as diarrhoea and respiratory infections and severe anaemia with high rate of mortality (WHO 2003b).

Table 6 Costs and benefits of rice paddy production with existing rainwater harvesting system, assuming that future climate change has not been taken into consideration with adaptation measures

	Units	Price/unit	Total value per year US\$ (2000 prices)					
			Year 1	Year 2	Year 3	...	Year 9	Year 10
<i>Revenue</i>								
Yield (kg/ha)	1,800	0.20	351.6	351.6	351.6	-do-	351.6	351.6
Total revenue (US\$/ha)(not discounted)			351.6	351.6	351.6	-do-	351.6	351.6
<i>Costs</i>								
Maintenance of cost of existing water storage			10.68	10.68	10.68	-do-	10.68	10.68
Plot renting (US\$/ha)	1	37.50	37.50	37.50	37.50	-do-	37.50	37.50
Seeds (kg/ha)	24	0.25	6.00	6.00	6.00	-do-	6.00	6.00
Fertilizer (bags/ha)	2	18.75	18.75	18.75	18.75	-do-	18.75	18.75
Tractor hiring charge (US\$/ha)	1	37.50	37.50	37.50	37.50	-do-	37.50	37.50
Hired labour (days/ha)	39	1.25	48.75	48.75	48.75	-do-	48.75	48.75
Family labour (days/ha)	183	0.33	61.08	61.08	61.08	-do-	61.08	61.08
Bags and twine	10	0.88	8.80	8.80	8.80	-do-	8.80	8.80
Transport			10.00	10.00	10.00	-do-	10.00	10.00
Total costs (US\$/ha)(not discounted)			257.76	257.76	257.76	-do-	257.76	257.76
Gross margin (US\$/ha)(not discounted)			94.0	94.0	94.0	-do-	94.0	94.0
Average farm/plot size	0.7							
Gross return to an average plot (Tsh)			66.0	66.0	66.0	-do-	66.0	66.0
Estimated annual volumetric water demand (use) (m ³ /ha)	13731							
Estimated annual volumetric water demand for the average farm size of 0.7 ha (m ³)	9611.7							
Productivity (value) of water (kg/m ³)	0.22							
Productivity (value) of water (US\$/m ³)		0.20	0.03	0.03	0.03	-do-	0.03	0.03

The calculations are based on data from Lazaro and others (2000) and Kadigi (2003)

Moreover, malaria infections in pregnant women frequently lead to a low child birth weight and this is a major risk factor in the first months of a child's life.

Element 3: Assessing the Relationship between Climate Variables and Development Indicators Related to Specific Activities It is expected that the distribution of malaria will be extended into new areas of the highlands and in some areas the season for malaria will be expanded with climate change. The incidence and distribution of malaria are affected by several factors including temperatures and precipitation patterns. Increase in the number of malaria incidences have been attributed to increased climate variability in several studies (WHO 2003a; Cox and others 1999; Zhou and others 2004; Wandiga and others 2006;

Abeku and others 2003; Githeko and Ndegwa 2001). Even small seasonal changes may create large adjustments in a number of malaria incidences (Fisman 2007). Based on this, it can be expected that increased temperatures can create malaria conditions in new highland areas which until now, due to low temperatures, have been unsuitable as malaria breeding grounds.

There are numerous development implications of malaria. These can be measured through direct and indirect costs (WHO 2003b). The direct costs involve personal expenditures such as purchase of bed nets and insecticides for treatment of the nets, mosquito coils, mosquito repellent lotions, aerosol sprays, anti-malarial drugs, transportation to health care facilities and the necessary

Table 7 Costs and benefits of rice paddy production with expansion of an existing rainwater harvesting system, assuming future climate change and adaptation measures

	Units	Price/unit	Total value per year US\$ (2000 prices)					
			Year 1	Year 2	Year 3	...	Year 9	Year 10
<i>Revenue</i>								
Yield (kg/ha)	3,000	156.25	585.94	585.94	585.94	585.94	585.94	585.94
<i>Total revenue (US\$/ha)(not discounted)</i>			585.94	585.94	585.94	585.94	585.94	585.94
<i>Costs</i>								
Investment cost, water storage (man days, family labour)	320	0.33	106.80					
Maintenance cost of water storage			10.68	10.68	10.68	-do-	10.68	10.68
Plot renting (US\$/ha)	1	37.50	37.50	37.50	37.50	-do-	37.50	37.50
Seeds (kg/ha)	24	0.25	6.00	6.00	6.00	-do-	6.00	6.00
Fertilizer (bags/ha)	2	18.75	18.75	18.75	18.75	-do-	18.75	18.75
Tractor hiring charge (US\$/ha)	1	37.50	37.50	37.50	37.50	-do-	37.50	37.50
Hired labour (days/ha)	39	1.25	48.75	48.75	48.75	-do-	48.75	48.75
Family labour (days/ha)	183	0.33	61.08	61.08	61.08	-do-	61.08	61.08
Bags and twine	10	0.88	8.80	8.80	8.80	-do-	8.80	8.80
Transport			10.00	10.00	10.00	-do-	10.00	10.00
<i>Total costs (US\$/ha)(not discounted)</i>			364.56	364.56	364.56	-do-	364.56	364.56
<i>Gross margin (US\$/ha)(not discounted)</i>			221.38	328.18	328.18	-do-	328.18	328.18
Average farm/plot size	0.7							
Gross return to an average plot (Tsh)			154.97	229.73	183,781	-do-	183,781	183,781
Estimated annual volumetric water demand (use) (m ³ /ha)	13731							
Estimated annual volumetric water demand for the average farm size of 0.7 ha (m ³)	9611.7							
Productivity (value) of water (kg/m ³)	0.22							
Productivity (value) of water (US\$/m ³)		0.20	0.04	0.04	0.04	-do-	0.04	0.04

The calculations are based on data from Lazaro and others (2000) and Kadigi (2003)

Table 8 The costs and benefits of implementing extended rainwater harvesting as an adaptation measure for rice paddy production, NPV's in US\$ 2000

Year	Benefits	Costs	Net benefits	Discounted net benefits	
				7%	15%
1	234.38	105.48	128.90	120.46	112.08
2	234.38	-1.32	235.70	205.87	178.22
3	234.38	-1.32	235.70	192.40	154.97
4	234.38	-1.32	235.70	179.81	134.76
5	234.38	-1.32	235.70	168.05	117.18
6	234.38	-1.32	235.70	157.05	101.90
7	234.38	-1.32	235.70	146.78	88.61
8	234.38	-1.32	235.70	137.18	77.05
9	234.38	-1.32	235.70	128.20	67.00
10	234.38	-1.32	235.70	119.82	58.26
NPV, US\$				1,555.61	1,090.03

supportive costs for the patient and caretaker. Indirect costs refer to productivity losses associated with morbidity and mortality. In the case of morbidity it involves the wage loss

or value of output associated with lost working time for each case and the costs of caretakers, school absenteeism and delayed investment opportunities.

In the case of mortality, lost income can be estimated by calculating the capitalised value of future lifetime earnings that would have been gained by those who died prematurely from malaria. Children who survive malaria may suffer long-term consequences of the infection since repeated episodes of fever and illness reduce appetite and restrict play, social interactions and educational opportunities, thereby contributing to poor development.

The most vulnerable to malaria are mainly children under 5 years and pregnant women. This example concentrates in the group of children below 5 years of age.

Element 4: Adaptation Options The use of malaria prevention is currently inadequate and an extension of preventive measures is expected to lead to considerable benefits. With extended use of malaria preventive measures as an adaptation option, a moderate level of malaria incidences can be obtained with consequential savings in lives lost and avoided morbidity together with substantial savings in treatment costs.

There are several adaptation measures, which can be applied to malaria prevention. One option is residential house spraying which involves treating all interior walls and ceilings with an insecticide, which is effective against mosquitoes that favour indoor resting before or after feeding. However, spraying has been abandoned or curtailed in many countries due to disillusionment over eradication results and to concerns over safety and environmental impacts. Administrative, managerial and financial constraints have also been an implementation barrier. Other options are malaria vaccine and medical prevention with chemoprophylaxis that is a presumptive intermittent treatment. However, this is not perceived as appropriate to the whole population. Lastly, insecticide treated bed nets (ITNs) is an option, which have shown to be an effective, feasible and economic attractive measure in reducing mortality and morbidity from malaria (Goodman and others 2001; Hanson and others 2003; Lengeler 2004; Mueller and others 2008; Mulligan and others 2008).

ITNs effectively provide a reduction in transmission intensity as they prevent mosquito bites and shorten the mosquito's life span, thereby reducing transmission (Brennan and others 2006). The beneficial impacts of large-scale ITN programmes have been demonstrated in Tanzania (Abdulla and others 2001; Armstrong-Schellenberg and others 2001a; WHO 2003a) and recently in Eritrea (Graves and others 2008) and expansion of ITN coverage is chosen as the adaptation measure in this example. A social marketing and distribution programme of ITNs in Tanzania (Armstrong-Schellenberg and others 2001b) has shown to reduce mortality among children under five with 20% and morbidity with 50%. Applying a 100% coverage ITN programme in Tanzania to this group of children could lead to 15,000 averted deaths and 3,195,000 averted cases according to the National Malaria Medium Term Strategic Plan 2002–2007, Ministry of Health in Tanzania (URT 2003) and a case study on the costs and consequences of a social marketing approach to malaria control in Tanzania in two rural districts by Hanson and others (2003) (see Table 9).

In order to evaluate benefits two different metrics are applied: disability-adjusted life years (DALYs) and value of statistical life (VOSL). DALYs are calculated as the sum of years of life lost due to premature mortality and the years lost due to disability for incident cases of the health condition. VOSL broadly measures the individual willingness-to-pay to reduce the risk of death and to small changes in mortality risks. Both metrics rely on economic valuation techniques and are associated with uncertainty due to lack of market prices. The valuation includes benefits associated with an improvement in health as well as health care costs and expenditures saved due to the improvement in health. It has been argued that the

Table 9 Overview of indicators related to malaria based on Hanson and others (2003) and URT (2003)

	Without extended ITN coverage	With extended ITN coverage
Children exposed to stable malaria transmission	7,100,000	7,100,000
Children with ITNs	5,325,000	7,100,000
No. of distributed ITNs	2,759,067	3,678,756
No. averted deaths	11,250	15,000
No. averted cases per year	2,396,250	3,195,000
No. of averted DALYs	310,300	413,733

willingness-to-pay for improved health may only include the welfare impacts due to illness and can thereby be criticised for discrimination against the poor who have less ability to pay due to their relatively low incomes. These limitations should be kept in mind in the economic valuation of the current example. The economic assumptions applied are shown in Table 10.

The benefits of the two scenarios that are shown in Table 9 are subsequently given in Table 11 and 12. The benefits include direct cost savings by reduced treatment costs and indirect cost savings in terms of DALYs and VOSLs, respectively. With a 20% effectiveness of ITN's on saved lives and 50% avoided cases, the project will result in additionally about 800,000 avoided cases and 3,750 extra saved lives. The benefit and cost estimates of the programme are calculated based on assumptions from Markandya (1998) and Hanson and others (2003) on the economic value of a VOSL on 87,970 US\$ and of a DALY on 57 US\$. Life expectancies are 54.2 years at birth and 58.6 years at the age of three. Calculation of VOSL is based on the ratio of real per capita GDP in Tanzania and adjusted to GDP in the US. By using real GDP it will take into account the purchasing power of the country, in this particular case Tanzania. Furthermore, it is assumed that insecticide lasts for 12 months. Malaria treatment costs are calculated based on a study by Jowett and Miller (2005) on treatment costs in Tanzania. Finally the treatment costs are discounted by 35% to account for non-compliance and smaller child doses.

The comparison of gross margins, using DALY, from scenarios with and without adaptation in Table 11, show

Table 10 Economic assumptions

	Value in US\$ (2000)
Benefit per DALY avoided	57
VOSL per person	87,970
Cost of treatment per treatment	0.747
ITN per net (including distribution costs)	6.7

Table 11 Baseline scenario without adaptation and scenario with adaptation, using DALY

	Without adaptation			With adaptation		
	Value per unit US\$ (2000)	Unit	Total value US\$ (2000)	Value per unit US\$ (2000)	Unit	Total value US\$ (2000)
Benefits						
DALY averted	57	310,300	17,687,100	57	413,733	23,582,800
Saved cost of treatment	0.747	2,396,250	1,789,999	0.747	3,195,000	2,386,665
Costs						
Distribution of ITN	6.7	2,759,067	18,485,751	6.7	3,678,756	24,647,668
Gross margins			991,347			1,321,797

Table 12 Baseline scenario without adaptation and scenario with adaptation, using VOSL

	Without adaptation			With adaptation		
	Value per unit US\$ (2000)	Unit	Total value US\$ (2000)	Value per unit US\$ (2000)	Unit	Total value US\$ (2000)
Benefits						
Saved lives	87.970	11,250	989,662,500	87.970	15,000	1,319,550,000
Saved cost of treatment	0.747	3,195,000	2,386,665	0.747	3,195,000	2,386,665
Costs						
Distribution of ITN	6.7	3,678,756	24,647,668	6.7	3,678,756	24,647,668
Gross margins			967,401,497			1,297,288,997

that the net benefit from the enhanced ITN programme is about US\$ 330,449 per year. Using the method of VOSL, net benefits are about 329,887,500 per year, which is substantially higher than the result with application of DALYs. This is shown in Table 12.

The above figures suggest that there potentiality are considerable benefits associated with up-scaling the use of ITNs in prevention, particularly if climate change will imply significant acceleration of malaria incidences. Expanded ITN distribution could in this case be a very attractive adaptation option.

Conclusions

The most important lesson learned from this paper is that adaptation is closely interlinked with focal development areas such as infrastructure, agriculture and health, and there is a large potential for integrating climate adaptation measures into already existing and on-going projects and planning efforts. In the case examples examined, integrating climate change adaptation could be done with a low cost.

Climate change mainstreaming has been addressed in a pragmatic way in the paper using a short list of sustainable development indicators to evaluate economic, social and environmental dimensions of climate change adaptation. The approach is stepwise and starts with modelling of climate conditions, variability and change, which subsequently are linked to development policies and indicators. This is followed by an identification of adaptation measures and assessment of these compared with unmitigated climate change impacts. The methodological approach is further illustrated in relation to three case studies from Mozambique and Tanzania.

The Mozambique example is related to infrastructure planning where existing and future highways can be damaged by increasing magnitude and intensity of floods. The damages will increase maintenance costs and can cause temporary disruptions on the roads. The highways could potentially be less vulnerable to climate change if adaptation measures, in terms of drainage systems, stronger foundations and bridges and alternative routes, were taken into consideration. Based on experiences from previous flooding events in 2002 in Mozambique and internationally available data on adaptation measures, it is shown that

there could be significant benefits associated with more climate safe road design.

Rainwater harvesting for agricultural irrigation have been considered as a case example for Tanzania, based on the expectation that agriculture in many parts of the country will need increased irrigation with climate change. The development impacts of enhanced rainwater harvesting capacity for rice paddy production are considered based on a previous study from the Dodoma region of Tanzania. Climate change was not taken into consideration in this study, however, an extrapolation of the cost and benefit results of enhanced irrigation measures in this case suggest that the rainwater harvesting systems are very effective in supporting crop yields and economic performance.

Increased malaria protection in Tanzania through increased distribution of bed nets has been considered as an adaptation measure against an expected increase of the incidence of malaria associated with climate change. The costs of malaria net distribution and information programmes are measured against avoided treatment costs and reduced sickness and mortality, and it is concluded that almost 4000 lives could be saved and 800,000 cases could be averted annually by distributing 800,000 additional net to cover the whole population in Tanzania. Such a program is considered to be very economically attractive and the net benefits were assessed to be 300,000 USD per year. Despite the potential large benefits of mainstreaming climate adaptation into malaria programmes, it should be noted that malaria protection planning in a climate context is as complex as in general malaria planning and there is no easy solutions in establishing not only knowledge but also utilization of interventions such as ITNs.

The approach in this way illustrates how sustainable development indicators and climate change can be linked, and quantitative information is provided about key linkages and impacts. A number of broader social impacts could be covered in more detail than it has been possible in the current case examples, and this could potentially further strengthen the argument that climate change adaptation measures could be important measures in reducing the vulnerability of the poor. This is the case because climate risks could be reduced for a relatively low cost in the examples, and because not coping with these could further enhance vulnerabilities in terms of poor health conditions for woman and children, weak infrastructure and flooding risks, and crop losses due to high variability of precipitation.

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