Tyndall°Centre
for Climate Change Research

# New indicators of vulnerability and adaptive capacity

W Neil Adger, Nick Brooks, Graham Bentham, Maureen Agnew
and Siri Eriksen

January 2004

Tyndall Centre for Climate Change Research Technical Report 7

# NEW INDICATORS OF VULNERABILITY AND ADAPTIVE CAPACITY

## TYNDALL PROJECT IT1.11: JULY 2001 TO JUNE 2003

**W. N. ADGER[1,5], N. BROOKS[1,5], M. KELLY[2], G. BENTHAM[3], M. AGNEW[3] AND S. ERIKSEN[4]**

## FINAL PROJECT REPORT

**January 2004**

**[1]Centre for Social and Economic Research in the Global Environment**
**School of Environmental Sciences**
**University of East Anglia**
**Norwich NR4 7TJ**
n.adger@uea.ac.uk/nick.brooks@uea.ac.uk

**[2]Climatic Research Unit**
**School of Environmental Sciences**
**University of East Anglia**
**Norwich NR4 7TJ**
m.kelly@uea.ac.uk

**[3]School of Environmental Sciences**
**University of East Anglia**
**Norwich NR4 7TJ**
g.bentham@uea.ac.uk/m.agnew@uea.ac.uk

**[4]Centre for International Climate and Environment Research - Oslo (CICERO)**
**Pb. 1129 Blindern**
**0318 Oslo**
**Norway**
siri.eriksen@cicero.uio.no

**[5]Tyndall Centre for Climate Change Research**
**School of Environmental Sciences**
**University of East Anglia**
**Norwich NR4 7TJ**

# OVERVIEW OF PROJECT WORK AND OUTCOMES

## NON TECHNICAL SUMMARY

There is an increasing need to develop indicators of vulnerability and of adaptive capacity both to determine the robustness of response strategies over time and to understand better the underlying processes. The climate change policy process has increasingly focussed on the potential for adaptation. National level indicators of vulnerability or adaptive capacity directed towards the allocation of resources to support financial mechanisms of the UNFCCC, for example, will only find acceptance if based on agreed criteria that are transparent and robust.

In this project we find that it is possible to compare the vulnerability of people and places across time and space at different scales. It is less meaningful to aggregate vulnerability across scales since the processes that cause vulnerability are different at each scale. We have explored issues of aggregation and construction of indices, weighting of indicators, and the efficacy of these to explain observed vulnerability to weather-related natural disasters. We are now in a better position to identify robust and transparent indicator sets. We find that national level adaptive capacity is dependent on social infrastructure and the accountability of institutions more than on the level of economic activity.

## OBJECTIVES

The goals of the project have been:

- to operationalise a database on quantitative socio-economic indicators of vulnerability to climate change, classified by particular categories of climate impact;
- to address two processes which shape vulnerability that we consider to have been inadequately studied in previous work: health status and social capital;
- to address the relationship between the indicators and theoretical models of adaptation relevant for incorporation into global integrated assessment models; and,
- to seek co-funding for expansion of the health and other components of the work.

## WORK UNDERTAKEN AND RESULTS

The first element of this project was the development of a conceptual framework within which indicators representing vulnerability and adaptive capacity could be developed. The conceptual framework was developed through a combination of literature review, attendance at meetings of practitioners in the field of vulnerability, adaptation and natural hazards, and discussions with key individuals. There are different views and definitions of vulnerability. This issue was addressed by combining the approaches of the climate change and natural hazards research communities, and developing a framework which related risk, vulnerability and adaptive capacity to one another, and which also addressed the issue of timescale.

The conceptual framework relates the concepts of vulnerability, risk and adaptive capacity to one another and reduces confusion between competing conceptions of the same issues in the domains of climate change and natural hazards and disaster management. The conceptual framework also provides a context within which indicators may be developed, and should enable researchers to be clear as to what they are developing indicators for.

The second element of the project involved the development of simple indicators of risk, measured in terms of the outcome of climate related disasters. This was achieved using data from the Emergency Events Database (EM-DAT). Countries were ranked by mortality outcome and combined mortality, morbidity and displacement outcome to climate-related events on a decadal basis. The work on outcome-based indicators of risk demonstrates that disaster data may be used to help our understanding of risk and vulnerability, although improvements in such data are desirable. Outcome data may be used as a useful tool in assessing the validity of proxies for risk and vulnerability.

The third element of the project was the development of predictive indicators of vulnerability (as opposed to diagnostic indicators of risk as described above), using publicly available data relating to social, economic, political and environmental factors. Once such indicators have been developed they may be used to identify areas for intervention in order to reduce the likelihood and severity of negative outcomes from future climate hazards associated with climate variability and change. Candidate proxy variables likely to represent elements of vulnerability were identified based on literature review and expert judgement, evaluated through correlation studies and other statistical techniques, and validated by an expert focus group.

The project results suggest that health, education, and particularly governance indicators, provide a reasonable assessment of vulnerability to climate hazards, at least in terms of mortality related to discrete extreme events. A number of health, education and governance proxies exhibit a strong relationship with mortality outcomes from climate related disasters when tested using data from the 1980s and 1990s. This result resonates with emerging insights, reviewed through the project, on the role of social capital and collective action as central to adaptation. These proxies can be used to construct indicators of vulnerability using a variety of approaches. Construction of composite indicators by averaging should be treated with caution; a better approach is to examine whether countries fall into categories of low, intermediate or high vulnerability for a variety of proxies in turn, and to assign scores for these categories which may then be summed to produce a vulnerability index. Disaggregated indices for different elements of vulnerability are more useful than a single index as they provide information on the structure of vulnerability. A simple modelling framework within which vulnerability indicators could be embedded has been proposed.

## RELEVANCE TO TYNDALL CENTRE RESEARCH STRATEGY & OBJECTIVES

This project is directly relevant to one of the seven key questions of the Tyndall Centre Adaptation Theme – ‘What influences the ability of institutions to adapt to climate change?’ The project has provided insights into the resources and processes that influence the ability of countries to adapt. The proposed modelling framework can be taken up by Theme 1 and in new research.

## POTENTIAL FOR FURTHER WORK

Future work can build upon analyses presented here by examining case studies in order to determine to what extent the results obtained here may be generalised. While indicators will play an increasingly important policy role, they capture only synoptic aspects of vulnerability at the scale at which they are applied. It is, therefore, important to develop our understanding of vulnerability by examining how it arises in a variety of contexts, paying attention to the relative importance of various social, economic, political, geographic and environmental factors in different countries, and also to the hazard-specific nature of vulnerability. The proposed modelling framework warrants exploration through a trial implementation. Three ongoing PhD studentships are exploring areas of this agenda, while the specific modelling areas are under development and may form the basis of a project proposal.

## TABLE OF CONTENTS

# TECHNICAL REPORT

## 1. INTRODUCTION

### 1.1. Background

As interest in climate change and its impacts has developed, the emphasis has shifted from an impacts-led approach to a vulnerability-led approach. The impacts led approach tends to concentrate on the evolution of physical hazards associated with climate variability, as a consequence of climate change. Typically this approach will examine future human exposure to climate hazards based on climate modelling studies and projections of population.

The vulnerability-led approach examines the underlying socio-economic and institutional factors, and, to a lesser extent, political and cultural factors, that determine how people respond to and cope with climate hazards. Studies of vulnerability may be carried out without a detailed knowledge of how climate will vary over time - we may assess the vulnerability of region, system or population group to a range of existing or hypothetical hazards based on an analysis of the factors that determine how it is likely to be affected should it be faced with the hazards in question. The vulnerability approach is therefore a useful tool with which to assess people's needs in terms of adaptation or improvements in their ability to cope with existing threats. Vulnerability assessments do not require detailed climate information generated by models (which is not available for many parts of the world), and they do not require us to wait until the science of climate "prediction" is more developed. Adaptation policies may therefore be developed despite the uncertainties inherent in the science of climate change - while a detailed knowledge of likely or potential future climate would be desirable, lack of it need not be an impediment to increasing the general resilience of societies to the types of threat that they may be expected to face in the future.

The IPCC Third Assessment Report (TAR) (IPCC, 2001) combines these two approaches, and this results in some confusion with two incompatible definitions of vulnerability being presented. The IPCC definitions and how to reconcile them by defining two different kinds of vulnerability are discussed below.

The IPCC TAR also introduces the concept of adaptive capacity into the mainstream of climate change research, and defines adaptive capacity as one of the determinants of vulnerability. However, vulnerability and adaptive capacity are described in rather general terms, and the way in which the relationship between them is mediated by the type of threats faced by systems is not explored.

In order to assess vulnerability and adaptive capacity in a quantitative manner we must develop indicators to represent these variables. However, for this to be possible we must first develop a coherent conceptual framework of vulnerability and adaptive capacity, before we can even begin to identify the factors that constitute vulnerability and adaptive capacity. Once we have developed such a framework and identified the elements of vulnerability and adaptive capacity we must choose appropriate proxies from which to construct our indicators.

Aside from the definitional and relational issues, we must also consider scales of analysis. We can assess vulnerability and capacity to adapt at a range of scales, from the household, through the local, regional and national, to the global. If we are concerned with a specific system or geographic area, we will perform our analysis at the scale at which that system is defined, or the scale that characterises the area in question. We might use quantitative indicators appropriate to the particular context, or we might undertake a more qualitative analysis of the factors that cause vulnerability and determine capacity to adapt. Such an approach will be appropriate for "self-assessment" exercises undertaken by businesses, regional or local governments, public utilities, and governments concerned with identifying vulnerable systems, regions and groups at the sub-national level.

An alternative approach is to construct comparative indicators that enable us to compare the vulnerability and adaptive capacity of different systems, groups or regions. We may adopt such a strategy to compare the vulnerability and adaptive capacity of different countries, through the use of national-level indicators. It is sometimes argued that the national level is not an appropriate scale for vulnerability analysis as vulnerability is highly context specific, and is spatially differentiated to a large extent within countries. However, vulnerability and adaptive capacity at the local level are influenced by processes operating at the national scale. For example, national economic policy can have a strong influence on the economic well-being of vulnerable groups, by determining the cost of basic needs such as food, education and healthcare, as well as the market price of commodities that form the basis of the livelihoods of vulnerable groups. Investment in crucial areas such as education, healthcare and physical infrastructure will also influence vulnerability by determining opportunities for vulnerability reduction and adaptation. The regulatory and taxation environment, set in most cases at the national level, will affect the possibilities for adaptation, and other processes driven by national policy will also play a major role. Agricultural policies will have a significant effect on the livelihoods and vulnerability of rural populations, and policies that encourage internal conflict or confrontations with neighbouring states will act to increase vulnerability to a range of hazards by causing instability, insecurity and the collapse of vital infrastructure.

We therefore develop indicators of the factors operating at the national level that act to ameliorate or exacerbate the vulnerability of a wide range of actors at the sub-national level. Similarly, national-level indicators of adaptive capacity will represent the factors and processes that act to facilitate or act as barriers to further adaptation. From the point of view of vulnerability reduction, the national level is an appropriate scale of analysis as it enables policy makers to identify interventions by government that will ameliorate vulnerability throughout society. Nonetheless, the potential for conflict must not be overlooked, as actions to reduce the vulnerability of one group may have negative implications for other groups - adaptation is likely to create winners and losers and this will have to be addressed through stakeholder engagement, conflict resolution and compensation schemes.

A number of existing studies of have employed national-level indicators in order to study phenomena such as environmental, vulnerability, human development and sustainability. These have involved the use of proxy data to represent factors such as environmental stress, poverty, inequality, health status and various aspects of governance. A host of other national-level data are available from which various indicators relating to governance, the state of the environment, and socio-economic and developmental conditions may be constructed. Other indicator projects, the choice of proxies for vulnerability and adaptive capacity indicators, and the construction of these indicators, are described in detail in section 2.4. below.

## 1.2. Objectives

The goals of the project have been:

- to operationalise a database on quantitative socio-economic indicators of vulnerability to climate change, classified by particularly categories of climate impact;
- to address processes which shape vulnerability that we consider to have been inadequately studied in previous work: health status and social capital;
- to address the relationship between the indicators and theoretical models of adaptation relevant for incorporation into global integrated assessment models; and,
- to seek co-funding for expansion of the health and other components.

## 1.3. Methodology

The main effort of the project, the development and evaluation of a vulnerability indicators database, has consisted of three principal elements.

The first element was the development of a conceptual framework within which indicators representing vulnerability and adaptive capacity could be developed. The conceptual framework was developed through a combination of literature review, attendance at meetings of practitioners in the field of vulnerability, adaptation and natural hazards, and discussions with key individuals. A key objective of the development of the conceptual framework was the reconciliation of different views and definitions of vulnerability. This problem was addressed by combining the approaches of the climate change and natural hazards research communities, and developing a framework which related risk, vulnerability and adaptive capacity to one another, and which also addressed the problem of timescale.

The second element of the project involved the development of simple indicators of risk, measured in terms of the outcome of climate related disasters. This was achieved using data from the Emergency Events Database (EM-DAT), obtained from the Centre for Research into the Epidemiology of Disasters (CRED). Data relating to disasters with a climatic component were extracted from EM-DAT, and countries were ranked by mortality outcome and combined mortality, morbidity and displacement outcome on a decadal basis. A major aim of this part of the project was to assess the usefulness of EM-DAT in examining outcome risk from climate hazards. Relationships between recorded disaster outcome and data coverage were therefore investigated.

The third and most important element of the project was the development of predictive indicators of vulnerability (as opposed to diagnostic indicators of risk as described above), using publicly available data relating to social, economic, political and environmental factors. Once such indicators have been developed they may be used to identify areas for intervention in order to reduce the likelihood and severity of negative outcomes from future climate hazards associated with climate variability and change. Candidate proxy variables likely to represent elements of vulnerability were identified based on literature review and expert judgement, evaluated through correlation studies and other statistical techniques and validated by an elite focus group.

In complementary work, an assessment of previous work on vulnerability indictors has been prepared, a discussion paper on the role of social capital is in press and case study material has been collated for use in the health component of the study. A collaborative proposal for further work on health aspects has been developed (see next section for further details). Finally, a simple modelling framework within which vulnerability indicators could be embedded has been proposed.

## 1.4. Dissemination of project results

Throughout the project the principal researchers have engaged with a variety of groups working in the field of vulnerability, adaptation and indicators.

Neil Adger and Nick Brooks were lead authors for a technical paper (Adger, Khan and Brooks, 2003) in the Adaptation Policy Framework (APF) of the United Nations Development Programme, and Nick Brooks participated in APF scoping and drafting meetings in London, Accra and Havana throughout 2002. The paper dealt with the assessment and enhancement of adaptive capacity, and the APF will be used as guidance by policy makers concerned with adaptation to climate variability and change at the national level.

Vulnerability to climate-related disasters is discussed in a book chapter, and outcome-based indicators of risk constructed from disaster data are discussed in a Tyndall Centre Working Paper for submission to a journal. A Working Paper on a conceptual framework of risk, vulnerability and adaptive capacity has been produced, and this will also be submitted to an international journal. A paper on the way in which hazard mediates the adaptation process, and on implications for measuring adaptive capacity, is in preparation. An assessment of previous work on vulnerability indicators has been submitted as a working paper. A number of other short communications, including a memorandum to the Parliamentary Committee on Sustainable Development, were also produced during the course of the project. A full list of publications, meetings and other outreach activities is presented below.

*Refereed articles*

Adger, W. N. and Brooks, N. (2003) Does global environmental change cause vulnerability to disaster? In Pelling, M. (ed.) *Natural Disasters and Development in a Globalising World*. Routledge: London, pp. 19-42.

Brooks, N. and Adger, W. N. (in revision) Country level risk measures of climate-related natural disasters and implications for adaptation to climate change. *Climate Research*.

Adger, W. N. (2004 in press) Social capital, collective action and adaptation to climate change. *Economic Geography*.

Dessai, S., Adger, W. N., Hulme, M., Köhler, J. Turnpenny, J. and Warren R. (in revision) Defining and experiencing dangerous climate change. *Climatic Change*.

Adger, W.N. (2004 in press) Vulnerability. In Forsyth, T. (ed.) *Encyclopedia of International Development*. Routledge: London.

Adger, W.N. (2003 in press) Social aspects of adaptive capacity. In Smith, J., Klein, R. and Huq, S. (eds.) *Developing Countries and Sustainable Adaptation to Climate Change*. Imperial College Press: London.

Sidle, R. C., Taylor, D., Lu, X. X., de Lange, W. P., Adger, W. N., Newnham, R. M., Lowe, D. J. and Dodson, J. R. (2003 in press) Interactions of natural hazards and society: evidence in historical and recent records. *Quaternary International.*

*Other material and papers in preparation*

Brooks, N. and Adger, W. N. 2003. *Country level risk measures of climate-related natural disasters and implications for adaptation to climate change*, Tyndall Centre Working Paper No. 26.

Adger, W. N. (2001) *Social Capital and Climate Change*. Tyndall Working Paper 8, Tyndall Centre, University of East Anglia, Norwich pp. 19.

Brooks, N. 2003. *Vulnerability, risk and adaptation: A conceptual framework*, Tyndall Centre working paper (currently under internal review).

Adger, W. N., Khan, S. R. and Brooks, N. 2003. Measuring and enhancing adaptive capacity, Technical Paper for Adaptation Policy Framework, UNDP, available at: http://www.undp.org/cc/apf.htm.

Adger, W. N. (2003) Building resilience to promote sustainability. *IHDP Update* **2/2003** 1-3.

Brooks, N. and Adger, W. N. (2002) Justice and science for sustainable development. *Science in Parliament* 59(3), 14-15. (reprinted in *Environmental Scientist*, 2002 11(6), 6-7).

Adger, W. N. and Brown, K. (2002) Examination of witnesses: N. Adger and K. Brown. In House of Commons, International Development Committee, *Global Climate Change and Sustainable Development*. HC Paper 519-II. Session 2001-02. The Stationery Office: London, pp 63-67.

Adger, W. N., Brooks, N. Brown, K. Conway, D., Haxeltine, A. and Hulme, M. (2002) Memorandum of Evidence on Climate Change and Sustainable Development by the Tyndall Centre for Climate Change Research. In House of Commons, International Development Committee, *Global Climate Change and Sustainable Development*. HC Paper 519-II. Session 2001-02. The Stationery Office: London, pp 59-62.

Berkhout, F., Jordan, A. Adger, W. N. and Moss, R. (2002) *Developing socio-economic scenarios for vulnerability and adaptation assessments*. Report for the 6th IPCC Task Group on Scenarios for Climate Impact Assessment 5-7th June, Helsinki, pp 5.

Eriksen, S. E. and Kelly, P. M. (2002) Vulnerability indicators and assessments – deitnfiying good practice. Submitted.

*Conference papers and meetings*

First Sustainability Days, Postsdam Institute for Climate Impacts Research, workshops attended: "Methods and Models of Vulnerability Research, Analysis and Assesment" and "Enhancing the Capacity of Developing Countries to Adapt to Climate Change," 28 September – 1 October 2001 (Presentations by Neil Adger and Nick Brooks).

UNDP APF scoping meeting, London 27-28 February 2002 (presentation by Nick Brooks).

UNDP Lead author meeting to elaborate an Adaptation Policy Framework, Accra, Ghana, 23-25 May 2002 (presentation by Nick Brooks).

WHO & London School of Hygiene and Tropical Medicine workshop: Floods: Climate change and adaptation strategies for human health, London, 30 June - 2 July 2002 (paper presented by Nick Brooks).

UNDP APF lead authors' meeting, Havana, Cuba, 12-14 September 2002 (presentation by Nick Brooks)

Meeting of Working Group III of the International Strategy for Disaster Reduction/UNDP, Geneva, 10-11 March 2003 (presentation by Nick Brooks).

Second Vulnerability Assessment workshop, Cranfield Disaster Management Centre, Coventry Univerisity, 7-8 May 2003 (presentation by Nick Brooks).

Adger, W. N., (2002) *Institutions for Adaptation to Climate Change: a Cross Country Analysis*. Paper presented at 'Environment and Development' International Society for Ecological Economics, Biennial Congress, 6-9th March 2002, Sousse, Tunisia.

Adger, W. N., (2002) *Social Resilience and Sustainability*. Presented at Sustainability Science: Knowledge, Technology and Institutions for Sustainability Transitions in Asia. 4-6th February 2002, Faculty of Social Sciences, Chiang Mai University, Chiang Mai, Thailand.

Tompkins, E. L. and Adger, W. N. (2003) *Re-thinking response capacity to enhance climate change policy development*. Paper presented at 'Mitigation and Adaptation in Climate Change' Conference, Centre for Advanced Cultural Studies, Essen, Germany, May 15-16, 2003

Adger, W. N. (2003) *Equity and vulnerability in Food Systems*. Paper presented at 'Vulnerability in Global Environmental Change and Food Systems', National Academy of Science, Washington DC, 15-16th January.

Tompkins, E. L. and Adger, W. N. (2002) *Building Resilience to Climate Change through Adaptive Management of Natural Resources*. UNDP Expert Group Meeting – Integrating Disaster Reduction and Adaptation to Climate Change, June 17-19, Havana, Cuba.

*Other outreach activities*

- Member of Scientific Steering Committee for NERC COAPEC (Coupled Ocean-Atmosphere Processes and European Climate) programme.
- Membership of Tyndall MRC-NERC Climate Change and Health Co-op.
- Research proposal on vulnerability to dust events and temperature extremes in North Africa in preparation with UEA Schools of Medicine and Development Studies (outcome of MRC-NERC co-op meetings).
- BBC Radio 4, Connect, Nick Brooks interviewed on subject of atmospheric dust, hazards and climate change
- BBC Radio 4, Home Planet, Nick brooks interviewed on subject of vulnerability to extreme weather events.

- Nick Brooks acted as consultant for and participated in a documentary about climate change and human occupation of the Sahara (produced by Fulcrum TV for Discovery US, Discovery Europe and UK Channel 5).

The work from this project has been utilised and has contributed to subsequent Tyndall projects and forms the basis of the work of three Tyndall affiliated PhDs:

- **Linda Sygna** is working on the importance of social capital in maintaining resilience in the post-socialist transition of Cuba and in resource management in Norway. This work is in collaboration with CICERO, University of Oslo and Linda is being co-supervised by Dr. Karen O'Brien from CICERO with Neil Adger at UEA.

- **Marisa Goulden** (ESRC/NERC Interdisciplinary Studentship) is working with Neil Adger and Declan Conway (DEV, UEA) on social capital in resource management strategies to cope with present day resource changes in wetland areas in Uganda. Here periodic environmental processes associated for example with ENSO events cause step changes in lake levels and hence in water availability over time. Social capital insights show how resilient the institutions and the resource base is when lakes exhibit flips in their equilibrium states (e.g. see Carpenter et al., 2000)

- **Katharine Vincent** (ESRC 1+3 Studentship) is beginning a PhD in 2003 on the importance of social capital in dryland resource livelihoods, focussed on southern African cases and examining the synergies between state facilitation of civil society in policy vacuums, such as those that are hypothesised to have occurred in post-1994 South Africa (see Evans, 1996). For her MRes thesis Katharine is developing vulnerability indicators for Africa.

## 2. PREVIOUS WORK ON VULNERABILITY INDICATORS

### 2.1. Introduction

There is a long history of vulnerability studies concerned with identifying those population groups most likely to experience the adverse effects of drought and other natural hazards or stresses induced by conflict or other social, economic or political forces in order to target effectively preventative measures and disaster relief (Mbithi and Wisner 1973, Kamau et al. 1989, Reardon and Matlon 1989, Cutter 1996, FIVIMS 2000, FEWSNET 2000). The focus of this body of work has, for the most part, been the developing countries and, given the nature of the impact, the spatial scale of these studies tends to be local to regional. The recognition of climate change as a global environmental threat has resulted in many assessments of the potential effects of climate change in different parts of the world (Jallow et al. 1996, Parry et al. 1999, Wilkie et al. 1999, Parry 2000, Sousounis and Bisanz 2000, Schiller et al 2001, often using vulnerability as a framing device (cf. the copious references to vulnerability in the chapter titles in the latest IPCC Working Group II assessment, McCarthy et al. 2001). For the most part, the results of these studies have been used to define the magnitude of the threat posed by the climate problem as a means of determining the need for political action to limit that threat. This assessment has been, unavoidably, of a rather general nature given the many uncertainties involved in forecasting future trends and the spatial scale has ranged from local to global. With the development of formal funding mechanisms, such as the Adaptation Fund (Huq 2002), specifically targeted at facilitating adaptive responses to the climate problem, which is synonymous with reducing vulnerability (Kelly and Adger 2000; Kelly 2001), the need for more formal assessment of differential levels of vulnerability has become pressing.

The demand for a more formal approach to vulnerability assessment brings with it a number of considerations that represent a challenge to existing practice.

First, there is pressure to go beyond local investigations of climate vulnerability to analysis at an aggregate level. The need to derive a global, or at least regional, overview of vulnerability and its development over time in order to understand the global problem of climate change has already created a demand for vulnerability assessment at the national level and above. Such exercises aim to accumulate and generalise our knowledge of how vulnerability is distributed and how it is developing throughout the world. The national level is often the favoured unit of analysis because it is hoped that certain indicators can be found that are comparable across nations and which are widely available. The nation-state level is also still the main political unit through which emission targets and adaptation policies are formulated and resources, such as development assistance, are assigned (Fermann 1997, Cooper 2000, Klepper and Springer 2003). It is the sovereign level at which international negotiations take place, and at which the ultimate responsibility for shaping the framework for policy formulation, instruments and institutional structures for executing measures lies.

Second, there is the desire for quantitative measures or indicators of vulnerability that can be used, for example, to allocate priorities for support between nations. For the most part, previous studies have abstained from developing measures of vulnerability itself, but have adopted indicators that capture the physical and/or social determinants or drivers of vulnerability (Kelly and Adger 2000).

Certain characteristics of vulnerability render meeting these requirements problematic, as discussed in detail in Section 2.5. First, vulnerability is geographically and socially differentiated. Any assessment at the national level must take account of regional patterns of vulnerability within the country and the distribution of vulnerability within the national community. It is also a function of processes operating in a range of scales, from the local, through the national to the global (Cash and Moser 2000), and any national measure must capture the influence of processes operating on all these scales. There is an inevitable tension as vulnerability is best defined at a point, at a particular location in space or within the community, and any aggregation to the national level can result in a loss of information. Second, it is increasingly recognised that vulnerability is a dynamic characteristic (Campbell 1999, Leichenko and O'Brien 2002), a function of the constant evolution of a complex of interactive processes (Smith and O'Keefe 1996, Kasperson

2001). Little is known, at present, about how this dynamism operates and plays out but this characteristic of vulnerability suggests that any measure or indicator should be capable of identifying both the steady-state situation and any trend in that situation. Finally, vulnerability is a result of complex and poorly understood interactions involving both physical processes and the human dimension. The social parameters of vulnerability, in particular, are not well defined (Kasperson *et al.* 2001; Schneider and Sarukhan 2001). Justifiable political sensitivities mean that the selection of appropriate indicators to represent this key aspect of the human condition requires extreme care.

### 2.2. A morphology of vulnerability indicator studies

The purpose of any study defines to a great extent the methods employed and the type of findings that are needed. We consider here three contrasting kinds of study whose purpose can be defined in terms of: 1) comparison between communities, nations or region; 2) general assessment of future threat; and 3) enhancing the understanding of the factors that determine vulnerability in order to identify measures to reduce vulnerability. There is, of course, considerable overlap between these categories in practice but each highlights particular characteristics of vulnerability or issues in vulnerability assessment.

In order to measure vulnerability comparatively with the goal of allocating resources effectively, the selection of indicators must be driven by trying to capture a snapshot of present-day exposure and capacity as precisely as possible. The focus here must be on the present-day if resources are to be committed in the here and now. Studies directed towards the allocation of resources at the national level, for example, to support financial mechanisms such as the Adaptation Fund intended to fund adaptation projects from the proceeds of the Clean Development Mechanism, highlight the need to agree indicators of present-day vulnerability. If the funding agency is "to make the, essentially political, judgement of which countries or regions are 'more' vulnerable than others" Huq (2002), then that judgement would be most likely to find acceptance if based on agreed criteria that are as transparent, robust and as close to objectivity as can be achieved. Vulnerability assessments at a sub-national level, such as those employed by Famine Early Warning Systems, have been tools to target intervention and aid at the most vulnerable areas and people as a famine develops. As a consequence, such studies have developed locally-specific indicators of adversity (rather than vulnerability *per se*) measuring emerging impacts, including food stocks, livestock and food prices and vegetation index aimed at directing public funds to regions most in need (Lonergan et al. 1999, FEWSNET 2000, Ramachandran and Eastman 2000, Zambia National Vulnerability Assessment Committee 2003). In selecting indicators of vulnerability in the contaxt of global warming, a future threat, the approach of using indicators based on observed impacts or adversity, is not, at this time, a viable option and analogues have to be used.

When assessing the magnitude of the threat of global warming, capturing local variability and pockets of vulnerability (closely related to the concept of criticality advanced by Kasperson et al. 1996, or so-called hotspots in relation to threats to biodiversity by Myers et al. 2000) becomes important. The effects of climate-induced pressures are unevenly distributed in time and space. Consequences vary between communities or social systems, between social groups in a community, between households and between people within a household (Downing 1992, Davies 1993, Guyer 1997, Adams et al. 1998, Morrow 1999). Scale issues become of vital importance when attempting to generalise, or select indicators, on scales greater than the characteristic scale of vulnerability hotspots (Turner 1991, Polsky and Easterling 2001, Stephen and Downing 2001, O'Brien et al 2003?). Any assessment of the overall threat posed by the climate problem must rest on identification of these hotspots and then on some form of accumulation or aggregation as necessary to whatever spatial scale is of ultimate concern. Studies vary in whether they deal with present-day or future patterns of vulnerability (Jallow et al 1996, Parry and Carter 1998, Kandilikar and Risbey 2000; Smith et al. 2000, Parry et al 2001). Clearly, estimates of future vulnerability, which must be the prime concern of this type of study, are contingent on uncertain projections of environmental change and socio-economic trends (Mitchell and Hulme 1999), though few studies have fully incorporated future socio-economic change (with some exceptions, such as Jordan et al. 2000) with most imposing the future environmental stress on present-day society.

Enhancing the understanding of vulnerability and the closely-related goal of identifying ways of reducing vulnerability clearly entail a focus on the causes of, or the processes shaping, vulnerability. To take one example of a process-based approach, the command over resources by individuals, households, social groups and communities is closely related to vulnerability. Command over resources affects both strategies to prepare for climatic events or change, such as investment in resistant agriculture, the ability to draw on alternative sources of food and income when the main source fails, and the ability to rebuild structural damage after a natural disaster (Gore 1993, Guyer 1997, Adger 2000). The concept of entitlement has been central in describing how people's command over resources is related to the ability to secure food or income. In particular, it is emphasised that while environmental factors may lead to a drop in food production, other social factors, such as market failure, determine whether or not a household can achieve food security (Sen 1981; Drèze and Sen 1989; Adger 1996). Food production decline can be an important cause of entitlement failure for small scale food producers who derive their entitlements from producing food; however, exchange entitlements decline, when prices of food soar and prices of assets plummet, is also important as demonstrated by, for example, Devereux and Næraa (1996) in their study of the 1992/1993 drought in Zambia.

The way in which command over resources is secured and the existence of opportunities when faced with a climatic event are determined in part by factors and processes that operate on scales higher than the household or community level. Jodha (1995) argues that fragile zones are characterised by environmental, economic and political threats that limit their opportunities. Famines or human adversity occurs in a broad political, economic and ecological context. Vestal (1991) argues that multiple natural and man-made phenomena, rather than one single cause, combine to produce famine. The underlying causes of individual entitlement or livelihood failure are the political and economic structures of resource ownership and control. Downing *et al.* (1995) suggest that human ecology, expanded entitlements and political economy and the place and time-specific configuration of these three key analytic variables define the dimensions of vulnerability.

From this brief survey of three different forms of vulnerability study, we can identify a number of characteristics of vulnerability and issues in vulnerability assessment that must be explicitly dealt with in selecting indicators. First, it is necessary to decide whether present-day or future vulnerability is the focus. Second, there is the need for precision, robustness, transparency objectivity and, if the indicators are to be accepted as a basis for decision making, recognition as valid by stakeholders. Third, scale issues are a critical concern. The fundamental scale of vulnerability, primarily because of differentiation within the community, is local, though processes operating at broader spatial scales do contribute significantly to patterns of vulnerability at the local level. The need to aggregate up to, say, the national scale requires careful handling as it can lead to the loss of information about vulnerability 'hotspots' and may even distort overall conclusions as detail is lost in the process of averaging or accumulation. Finally, we would argue that the selection of *robust* indicators, whether the purpose of the study, should be based on understanding of the multiple processes that shape vulnerability. While most studies do, in justifying the choice of particular indicators, put forward process-oriented arguments, understanding of the factors that shape vulnerability is limited and such arguments are too often based on theory or supposition alone.

### 2.3. Indicator selection

Procedures for indicator selection follow two general approaches, one based on a theoretical understanding of relationships and one based on statistical relationships. Conceptual understanding does, however, play a role in both. The first approach represents a deductive research approach and the second an inductive research approach.

The deductive approach to selecting indicators involves proposing relationships derived from theory or conceptual framework and selecting indicators on the basis of these relationships. The first step in a deductive or theory-based approach is understanding the phenomenon that is being studied and the main processes involved. The second step involves identifying the main processes to be included in the study and how they are related. The third step involves selecting the best possible indicators for these factors and processes and assigning values and weights. During this procedure, conceptualization, or identifying key concepts and the relationships between them takes place, and the research questions and hypotheses are stated.

Concepts need to be operationalised in order to test variables empirically. Operationalising involves the specifying of how theoretical concepts will be measured, in other words "indicators that will be used to measure the concept to produce data on it" (Blalock 1984, p. 133-4). In deductive research, a hypothesis is tested by operationalising the concepts in the hypothesis and collecting the appropriate data to explore the relationship between the measures of these concepts. A strong conceptual framework can form the basis for identifying vulnerability indicators. Downing et al (1995), for example, conceptualise vulnerability as depending on human ecology, expanded entitlements and political economy. This drives their selection of indicators measured, namely, food availability in kcal/ day per capita, GNP per capita, and under 5 mortality per 1000. The significance of the findings from this study can be assessed on the basis of the validity of theoretical approach and assumptions, the appropriateness of the selected indicators and the reliability of data.

The statistical procedure to selecting indicators involves relating a large number of variables to vulnerability in order to identify the factors that are statistically significant. In a sense, an inductive approach involves a ‘hoovering’ of potentially relevant indicators and selecting indicators on the basis of significant statistical relationships. The observed statistical relationships are then used to build a model. As such, the deductive and inductive procedures to identifying indicators have a parallel in the two types of climate modelling, that is dynamic modeling, based on our understanding of physical relationships, and statistical modeling, based on observed empirical relationships. The use of a conceptual framework and operationalisation is less rigorous in inductive research than in deductive methods, and the testing of hypotheses is less formal. Some concepts are often considered at the outset, however, in order to frame the collection of data.

Inductive research often uses empirical generalisations, filled with empirical content and statements of empirical regularities. Theory consists of generalisations derived by induction from data: in other words, the finding of patterns in data that can be generalised. Ramachandran and Eastman (1997) applied 92 variables used with 539 potential values for each variable (seven years across 77 administrative sub-divisions) to explain the average number of people in need of food assistance in West Africa. Indicators regard Normalised Difference Vegetation Index, prices of livestock and food grains, agricultural production, demographic data and large-scale agricultural survey results. Through statistical methods, the different contributions of different variables to vulnerability were assessed.

It is characteristic of many vulnerability indicator studies that they do not belong distinctly to either a deductive or an inductive approach. Many studies base their selection of a multitude of indicators on a basic theoretical understanding of vulnerability (such as that vulnerability is a result of high exposure to a hazard and low coping ability, Ramachandran and Eastman 1997, or of sectoral sensitivities and coping and adaptive capacity, Moss et al. 2000) and identify categories of indicators (such as settlement/infrastructure sensitivity, food security, economic capacity, human and environmental resources, national economic growth and human development, Moss et al 2000, Kanamaru 1998). Few studies thoroughly discuss how these categories are linked theoretically and conceptually to the basic understanding of vulnerability or explicitly utilize theory to inform further indicator selection within each category, as recommended by Lonergan et al. (1999).

Studies that closely integrate theory, conceptualization and indicator selection are more commonly performed at the sub-national level, such as a case study of Georgetown County, South Carolina (Cutter et al. 2000) and a study of three global coastal cities (Schiller et al. 2001). Schiller et al., for example, conceptualizes the relationship between stresses and an exposed system, suggesting that endowments, direct coping abilities and indirect coping (social safety net/support, social contact) are important components of system characteristics and selecting indicators for each of these components. Similarly, the selection of indicators in a study on sub-national level in Vietnam is based on a theoretical framework conceptualizing, operationalising and measuring individual and collective vulnerability as main elements of social vulnerability (Adger 1999; Adger and Kelly, 1999; Kelly and Adger 2000).

While employing a looser conceptual framework is consistent with inductive research methods, national level indicator studies seldom relate the distribution of vulnerability in time or space statistically to an end-result adversity or other independent measure of vulnerability. Among the clearer examples of an inductive approach is the study by Kamanou and Morduch (2001) regarding vulnerability to poverty in Côte d'Ivoire, in which regression models are built, though, again, the study focuses on households rather than the national level. Per capita expenditures, household size, age of head, gender of head, marital status of head, region, education of head, nationality, and literacy and numeracy are selected as indicators of vulnerability and statistically related to consumption. The next step in an inductive approach would be assessing the extent to which the findings can be generalized, and explaining the relationships that make the identified variables important determinants of vulnerability.

Finding a meaningful measure of end-result adversity or vulnerability at the national level against which vulnerability indices can be run to form statistical relationships is a major challenge in inductive studies. Databases regarding mortality and the numbers of people adversely affected by climate-related events have poor data coverage for certain time periods and countries (Brooks and Adger 2003). Other data more appropriately representing the severity of impacts of climate-related disasters, such as data on economic damage, are sparse and are also difficult to estimate and data insurance claims may over-emphasise impacts on wealthy nations as these are the ones who have the greatest material losses in terms of insured economic values. The actual material losses and threats to livelihoods experienced by uninsured poorer households in developing countries, are not captured (German Committee for Disaster Reduction 2002, Münchener Rückversicherungs-Gesellschaft 2002, Brooks and Adger 2003).

### 2.4. Challenges in designing vulnerability indicator studies

We now consider three characteristics of vulnerability and vulnerability research that present particular problems when devising vulnerability indicators: scale issues; dynamism; and complexity and limited understanding.

There are several considerations that need to be made when employing the national level for vulnerability analysis. Vulnerability is manifested at a point in space and time as a particular state. As discussed above, the state of vulnerability, as well as closely related states such as poor command over resources, vary in space and in time. We suggest, therefore, that national level indicators seek to capture processes that shape vulnerability rather than to try to aggregate the state itself. Local level studies of vulnerability and the factors that lead to vulnerability can, however, form a useful starting point in distinguishing such processes.

There are, for example, variations in the extent to which households are endowed with resources and the ability to convert these into food entitlements. Studies on patterns of coping emphasise that people draw on a number of informal sources of food and income, such as social networks (Davies 1993, Swift 1993, Pottier 1988, Homewood 1995, Morrow 1999). Individuals in a household vary in knowledge, skills, culturally and socially determined rights to resources (be it labour resources, monetary resources, agricultural production, water of forest resources) according to gender and age (Nypan 1991, Denton 2002, Cannon 2002). Coping strategies seek to balance present consumption with future livelihoods and are generally sequenced reflecting increasing present adversity and compromising of future livelihoods as a drought progresses, as observed by Corbett (1988). While coping strategies are aimed at minimising the intensity and duration of crisis by maximising limited resources, households vary in their capacity to mobilise and manage resources and thus ability to cope. Watts (1983) found substantial differences in the way that households at different income levels cope with drought, the rich even being able to profit from stocking food and hiring labour at deflated prices. The comparative advantage of households who possess particular skills or endowments of labour which obtains higher returns in some activities is an important factor in determining income diversification (Dercon and Krishnan 1996) and main reasons for differences in success to survive environmental pressures (Anderson and Woodrow 1991; Stigter 1995). Further, on a community level, social and organisational capacities, such as in decision-making, and attitudinal and motivational capacities, such as shared belief systems, influence the capacity to respond to a drought (Davies 1993).

The selection of national level indicators may focus on processes that shape these variations in time and space. Some examples of processes that are relevant to adaptive capability are listed in Table 1. It has been argued, for example, that traditional systems of social security in Third World societies may be in the process of being eroded due to the joint impact of market penetration (reorientation of most production away from local circulation and reciprocity), population growth (fewer unappropriated flexible resources) and rise of the modern state system (provides services) (Platteau 1991). Other processes that contribute to increasing vulnerability are the privatisation of land and degradation of common lands (Jodha 1990), loss of diversity in livelihoods (Netting 1993, Ellis 1988) or the declining health status of the population (UN Office for the Coordination of Humanitarian Affairs 2003).

The processes that shape vulnerability operate on different geographic scales. While decreasing labour availability is a process that may manifest itself on a community level, a national level indicator may aim to capture the processes that shape local level decrease in labour availability, such as urbanisation and deagrarianisation. A community, in this context, refers to looser forms of social organisation in which either space or common interests are the defining characteristics (Blaikie 2000). Taylor and Flint (2000) argue that the national level of analysis in political geography is promoted as a middle category to separate conflicting interests. The nation-state functions as a broker between global and local scales. Local level is the level of experience (or impact) and the global level is the level of reality (where many influencing processes operate). The nation-state thus represents a scale of ideology that separates the scale of experience from the scale of reality. State sovereignty is increasingly limited by the activities of transnational corporations involved in production, trade and finance (Fermann 1997). In addition to globalisation, the process of localisation affects the traditional role of the nation as a provider of security to individuals and it is individuals and communities rather than nation-states who face the greatest risks (Lonergan et al. 1999). While the national level may be useful for descriptions and international comparisons of vulnerability, any analysis at this level may need to take into account other levels, both in understanding international trends and processes affecting vulnerability (Leichenko and O'Brien 2002) and local differentiation in vulnerability that is masked by a national characterisation or indicator (Brooks and Adger 2003). Of course, a study that employs the national economy or the nation-state as unit of investigation, rather than humans, will make different considerations regarding scale, given that the unit of focus regarding potential adverse effects is the nation itself, and not people within it.

It is important to note that the discussion above does not represent an exhaustive list of all factors that determine vulnerability; indeed, it is intrinsic in the dynamism of vulnerability that there is a great variety of such factors and that these factors are changing all the time. Any indicator study of vulnerability has to tackle this dynamic structure of vulnerability. Lonergan et al. (1999) suggest that studies aimed at identifying vulnerable regions should include both driving force indicators, that reflect key structural relationships and state indicators that reflect functional relationships and process flows within the system.

There are two aspects to dynamism critical to indicator studies: first, that local capacity and command over resources and thus vulnerability are shaped by processes and thus vary in time and space as alluded to above; and second, that individuals, households, social groups and communities may be faced by multiple pressures at the same time, in addition to climate change, such as economic change or political conflict (de Waal 1989, Lonergan *et al.* 1999). O'Brien and Leichenko (2000) describe Africa as an example of a geographic area that may be experiencing synergistic negative effects from two processes, that is, economic globalisation and climate change. Africa has a low share of world trade and the economic growth that may accrue from such trade. In addition, two thirds of the land is arid or semi-arid, many areas experience high interannual climate variability and climatic events such as droughts and floods, there are high levels of poverty and a high dependence on agriculture. The situation is heterogeneous within the continent, however, with great variations between sectors, regions and population groups in terms of negative or positive effects derived from economic globalisation and climate related changes. The US, a country with a high share of the world trade and economic growth, provides a stark example of the heterogeneity between population groups and regions in the effects of climate change and economic globalisation. Processes of globalisation and reduced demand for low-skilled labour have led to spatial concentration of poverty within central city areas. These residents of poor inner-city communities in large US cities are also among the most vulnerable to heat waves due to lack of money to pay for air-conditioning and summer heat-related mortality may increase with global warming (O'Brien and Leichenko 2000).

**Table 1: Examples of processes that affect vulnerability***

| Local scale processes (e.g. household or community) | Processes at higher scales |
|---|---|
| Increasing labour migration | Population growth |
| Declining labour availability | Increasing/decreasing provision of services by the state |
| Loss of customary rights and change to 'modern' tenure systems | Increasing penetration of global markets/ Reorientation of most production away from local circulation and reciprocity |
| Reduction of mobility in terms of grazing livestock | Relative declining value of rural products, both agricultural and nonagricultural |
| Increasing need for cash | Changing legislation and tenure systems |
| Increasing price of inputs | Declining biodiversity and forests/expansion of agriculture |
| Privatisation of land and resources | Declining indigenous knowledge |
| Monetarisaiton of resources and services/ increasing health and education costs | Increasing HIV/AIDS prevalence |
| Loss of access to communal resources | Urbanisation |
| Increasing skills requirements for nonagricultural employment | Deagrarianisation |

*The distinction made between processes operating at local scales and processes operating at higher scales is to some extent arbitrary as some processes may be operating on several scales.

The dynamic character of vulnerability leads to a complexity, in terms of processes interacting at several different geographic scales, that has to be tackled by national indicator studies. Because vulnerability cannot be measured directly, indirect measurements through a focus on processes shaping vulnerability needs to be accommodated both in the use of deductive or inductive research approaches. Blalock (1984) argues that when links between phenomenon are well understood, measurement can be direct, but that in social sciences, causal laws are multivariate and indeterminate.

The complexity may render it tempting to give up conceptualising the understanding of vulnerability that underlies the analysis. Precisely because of the complexity, however, it is all the more important to outline a conceptual framework so that assumptions and weaknesses in understanding can be assessed. A crucial aspect in defining indicators that are essentially trying to capture the causes of vulnerability is that the relationships between vulnerability and the factors shaping vulnerability need to be well understood and the assumptions about these relations made explicit.

Inevitably, not all aspects of the relevant phenomenon can be selected for study. Simplifying assumptions will, therefore, always be necessary. Though the breaking down of complex systems into components has sometimes been criticized as reductionist, simplification enables the investigation of some of the most important interactions. Indicators of sustainability, for example, attempt to capture complex and diverse processes in relatively few measures (Bell and Morse 1999). There may not be agreement on which assumptions to use, nor may they be obvious or made explicit. "Measurement decisions then become much more problematic and seemingly arbitrary. It should come as no surprise, then, to find social scientists in sharp disagreements both about the measures of specific variables and the more general problem of whether or not measurement issues should be seriously addressed at all" (Blalock 1984, p. 49). Shortcomings in the assumptions may produce serious flaws in the entire argument. The theory interrelating the several postulated causes therefore has to be well specified and assumptions well understood in order for an indicator study to be verifiable and comparable and in order to allow the improvement and updating of such exercises when new knowledge about vulnerability becomes available.

Because research problems are often unclear, taking care in perceiving the problem becomes all the more important, making the process of thinking about the problem iterative, participatory and ongoing (Bell and Morse 1999). Defining the system and developing conceptual models in order to enable transparency and testing of assumptions are crucial aspects of this procedure.

The development of a conceptual framework is particularly important in national level indicator studies because these often use aggregate data. Retzlaff (1968) argues that when comparing areal units, such as states, the attributes of these areas are different from the sum of attributes of individuals within them. In his review of work by Karl Deutsch, Seymour Martin Lipset and Phillips Cutright, Retzlaff identifies four areas of consensus regarding the use of aggregate data in comparative political analysis. First, the development of a conceptual framework is essential in facilitating the use of aggregate data. Second, the conceptual tools that are developed need to recognize the multi-variate character of the processes under analysis. Third, index formulation is a central theme, though taking account of weighting, correlation between variables and threshold values is problematic. Finally, changes in the political system and changes in the social and economic systems are interrelated.

## 2.5. Implications for best practice in indicator studies

From the above discussion, ensuring that assumptions in the selection of vulnerability indicators are made explicit, and conceptualisation as a means of achieving this, emerge as important elements in a procedure for measuring vulnerability. In particular, the national scale of analysis necessitates a clear understanding of the processes that are attempted captured in such an approach. The verification of a conceptual framework, is an important means of improving understanding and representation of processes in indicator studies. To what extent do the indicators represent driving forces of vulnerability, and to what extent does the indicator study provide meaningful and valid results regarding vulnerability? This question is as important for studies aimed at comparing between nations forming part of a justification for allocation of resources as it is for studies aimed at measuring the scale of the threat or enhancing the understanding of vulnerability.

Study findings can be evaluated not only according to whether they appear plausible, but more specifically through comparisons with the outcome of other relevant studies. Few vulnerability indicator studies have been carried out so far at the national level; therefore, it may be necessary to compare indicators studies specifically focusing on vulnerability with indicator studies focusing on related issues, such as poverty (Sahn and Stifel 2000), human development (UNDP 1996, World Bank 1997) or environmental sustainability (World Economic Forum 2000) as well as studies focusing on the sub-national scale (Adger 1999) and qualitative and expert judgement data (Parry and Carter 1998, Parry 2000).

In the deductive research approach, verification involves assessment of the goodness of fit between theoretical predictions and empirical evidence. The selection of indicators and the measurement process represent a theoretical reasoning and prediction (Blalock 1984). Vulnerability itself is a state of potential adversity; thus, deductive approaches can be tested against one or more actual outcomes of climatic events in terms of adversity, an analogue of possible future conditions (Parry and Carter 1998). Actual adversity encountered in connection with a particular event itself can be measured more or less directly using well established measures, such as death, illness, hunger or loss of property (FIVIMS 2000, Brooks and Adger 2003). Such a test is highly context specific given that the dynamic nature of vulnerability cannot be fully captured by a snapshot in time. Parry and Carter also suggest that analysis tools can be tested and evaluated through conducting ‘microcosm’ case studies, small-scale pilot studies under conditions representative of the main study.

While conceptualisation is less rigorous in inductive research approaches, such analyses seek patterns in the data. The explanation of these patterns may form the basis for assessing indicator studies of this kind. Identifying good explanations for the factors found to statistically explain vulnerability supports/strengthens that appropriate indicators have indeed been found and that results are meaningful.

One of the main challenges that indicator studies face is that of finding reliable data (Parry and Carter 1998). Few studies have so far been able to carry out a verification step comprehensively partly due, perhaps, to the limitations of disaster data as discussed above. In addition, there are few national level comparative data sets that refer to past events rather than average levels over time or ongoing monitoring concerning many of the key adverse consequences that are envisaged as possible results of climate change, including deteriorating food security or increasing undernutrition and other health problems (Haddad et al. 1994, Parry et al. 1999, McCarthy et al. 2001).

The need to verify vulnerability assessments is particularly great given the complexity of vulnerability, assumptions made, as well as variations in definitions of vulnerability and theoretical approaches applied. Different studies may use different indicators and produce differing findings regarding national level vulnerability, with none likely to produce the ultimate and definitive answer. It is important to be able to interpret what aspect of vulnerability that each study describes so that different study findings can complement each other and enhance total understanding of vulnerability. In addition, identifying the shortfalls and potential for improving the indicator selection and such assessments is crucial. The outcome of the test may identify weaknesses or scope for improvement in any one of the steps in indicator selection, including definitions of vulnerability, theoretical approaches and assumptions made, conceptualisation, operationalisation, weighting, and data collection and analysis.

**Table 2: Facets of vulnerability studies:**

| **Facet** | **Example** |
|---|---|
| Purpose | Comparison<br>Assessment of threat<br>Enhanced understanding of causes (and identification of measures to reduce vulnerability) |
| Definition of vulnerability | Yes/no |
| Scale | Scale at which processes operate<br>Unit of investigation/unit at threat |
| Dynamism | Multiple pressures<br>Processes affecting factors of vulnerability |
| Conceptual framework | Yes/No<br>Assumptions transparent? |
| Research approach | Deductive/Inductive<br>(Subjective/objective)<br>Statistical/processbased. |
| Data | Reliable and representative,<br>Selection of indicators defensible to community/ stakeholders?<br>Reproducibility |
| Verification | Evaluate validity and plausible outcome<br>Compare with findings of relevant studies<br>Analogue past event<br>Case study<br>Explaining relationships |

The above discussion has shown that there are several aspects of indicator studies to which careful attention should be paid in striving for good practice, given the particular characteristics of vulnerability. An indicator study has to tackle the dynamic structure of vulnerability. We suggest that in order to meet this challenge, the selection of national level indicators should focus on processes that shape variations in time and space. The selection of indicators needs to take account of the fact that the multiple processes that shape vulnerability operate on various geographic scales. Simplifying assumptions will always be necessary and selecting indicators implies selecting the particular processes deemed most important in shaping vulnerability. It is important that these assumptions are made explicit. There is no commonly accepted set of indicators and identifying any set designed to represent vulnerability is very challenging. By ensuring that methods of indicator selection are transparent, both the methods and findings can meaningfully be compared and assessed, so that studies can complement each other, the understanding of vulnerability be enhanced, and any weaknesses in methods be identified and addressed. To put it simply, since studies are likely different aspects of vulnerability of processes leading to vulnerability, it is crucial to be able to identify which aspects are studied, what the findings say about these aspects, and whether findings regarding these aspects are reliable.

We suggest that such transparency would be aided by paying attention and being explicit about the specific choices made in any particular study, outlined in Table 2 above. It is important to select and define the relevant concepts before the research commences, both in inductive and deductive research. Transparency in the theoretical and conceptual understanding that underlies indicator selection is important because there is inevitably a varying degree of subjectivity in the assumptions made. Lack of democracy as an indicator of vulnerability, for example, is a normative partly subjectively derived measure. Subjectively derived measures are useful “if the subjectivity is explicitly accepted and declared at the outset and if the method for deriving the measures are available to a range of stakeholders" (Bell and Morse, p. 103). In past studies, the link between the theoretical understanding, conceptual framework and selection of indicators are often not sufficiently explicit. It is, therefore, unclear whether divergent findings (alternatively faulty findings and methods) can be ascribed to the theory or conceptual framework, the selection of indicators, or the data.

In addition to transparency, verification of findings is an aspect of vulnerability indicator studies to which insufficient attention has been paid. Inductive studies need to be able to explain the processes and relationships that lead to the identified patterns of vulnerability and statistical relationships, including why particular indicators are found to be significant in explaining vulnerability and others not. Deductive indicator studies can be verified by testing the outcome against a ‘reality’, most often a snapshot in time of the effects of a particular event, or case studies of interactions of processes hypothesized to be shaping vulnerability. It needs to be kept in mind that these are only snapshots, however. This calls for continuous monitoring of the processes that lead to vulnerability, such as loss of diversity in livelihoods or declining health status of the population. Such a monitoring differs from conventional famine monitoring studies in that emphasis is shifted to monitoring of the processes rather than of the outcomes; for example, on the loss of diversity in livelihoods rather than local food prices and stocks.

The focus on processes and verification in indicator studies underwrites the need to enhance understanding of how processes operate to shape a dynamic vulnerability. Further methodological development may address the ways in which quantitative and qualitative methods and information can be combined in indicator research and, as suggested by Lonergan et al. (1999), frameworks that can deal with both types of indicators.

## 3. DEVELOPMENT OF A CONCEPTUAL FRAMEWORK

### 3.1. The need for a conceptual framework

Vulnerability is not a straightforward concept, and there is no consensus as to its precise meaning. As discussed below, some definitions of vulnerability are contradictory, and the term is used to mean different things by different authors. Similarly, the term "adaptive capacity" is used to cover a multitude of factors, but there is no general agreement as to what these factors should be. Neither is there much in the published literature regarding the relationship between vulnerability and adaptive capacity; the former is described variously as the inverse or as a function of the latter. Crucially, vulnerability and adaptive capacity are often discussed without any explicit consideration of how they are mediated by the nature of the (e.g. climate) hazards faced by a vulnerable system, and by the timescales over which these hazards operate.

In addition to causing a great deal of confusion among researchers, development agencies and policy makers, the lack of a coherent conceptual framework relating vulnerability, adaptive capacity and other important concepts such as risk makes the task of choosing indicators rather problematic. The question of what factors constitute vulnerability and adaptive capacity, and why, is crucial if we are to attempt any sort of quantitative or semi-quantitative measurement of these variables.

### 3.2. Definitions of vulnerability

There are many different definitions of vulnerability, and it is not the intention here to review them all. For a summary of definitions of and approaches to vulnerability the reader is directed to Adger (1999). Broadly speaking, the vulnerability of a system, population or individual to a threat relates to its capacity to be harmed by that threat. Social scientists and climate scientists often mean different things when they use the term "vulnerability". Whereas social scientists tend to view vulnerability as representing the set of socio-economic factors that determine people's ability to cope with stress or change (Allen, 2003), climate scientists often view vulnerability in terms of the likelihood of occurrence and impacts of weather and climate related events (Nicholls *et al.*, 1999).

It is essential to stress that we can only talk meaningfully about the vulnerability *of a specified system or exposure unit to a specified hazard or range of hazards*. A system or exposure unit may be a region, population groups, community, ecosystem, country, economic sector, household, business or individual. The term *hazard* is used here to refer specifically to a physical manifestation of climatic variability or change, such as a drought, flood, storm, episode of heavy rainfall, a long-term change in the mean value of a climatic variable, a potential future shift in a climatic regime and so on. Climate hazards may be defined in terms of absolute values or departures from the mean of variables such as rainfall, temperature, wind speed, or water level, perhaps combined with factors such as speed of onset, duration and spatial extent. Hazards are also referred to as *climate events*. Crucially, hazards as described here are purely physically defined. A *disaster* as measured in human terms (lives lost, people affected, economic losses) is therefore the *outcome* of a hazard, mediated by the properties of the human system that is exposed to and affected by the hazard.

### *Social and biophysical vulnerability*

Definitions of vulnerability in the climate change related literature tend to fall into two categories, viewing vulnerability either (i) in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer, 2003), or (ii) as a state that exists within a system before it encounters a hazard event (Allen, 2003). The former view has arisen from an approach based on assessments of hazards and their impacts, in which the role of human systems in mediating the outcomes of hazard events is downplayed or neglected. Climate change impacts studies have typically examined factors such as increases in the number of people at risk of flooding based on projections of sea level rise (e.g. Hareau et al., 1999; Nicholls *et al.*, 1999), and have thus focused on human *exposure* to hazard rather than on the ability of people to cope with hazards once they are manifest. The hazards and impacts approach typically views the vulnerability of a human system as determined by the nature of the physical hazard(s) to which it is exposed, the likelihood or frequency of occurrence of the hazard(s), the extent of human exposure to hazard, and the system's *sensitivity* to the impacts of the hazard(s). This view is apparent in the principal definition of vulnerability in the IPCC Third Assessment Report (TAR) (IPCC, 2001a), discussed in more detail below. This combined vulnerability, a function of hazard, exposure and sensitivity, is sometimes referred to as *physical* or *biophysical vulnerability* (O'Brien et al., 2003). The term "biophysical" will be used here, as it suggests both a physical component associated with the nature of the hazard and its first-order physical impacts, and a biological or social component associated with the properties of the affected system that act to amplify or reduce the damage resulting from these first-order impacts. Biophysical vulnerability is concerned with the ultimate impacts of a hazard event, and is often viewed in terms of the amount of damage experienced by a system as a result of an encounter with a hazard. Jones and Boer (2003) are therefore referring to biophysical vulnerability when they state that "Vulnerability is measured by indicators such as monetary cost, human mortality, production costs, [or] ecosystem damage…"

Conversely, the view of vulnerability as a state (i.e. as a variable describing the internal state of a system prior to the occurrence of a hazard event) has arisen from studies of the structural factors that make human societies and communities susceptible to damage from external hazards (Allen, 2003). In this formulation, vulnerability is something that exists within systems independently of external hazards. For many human systems, vulnerability viewed as an inherent property of a system arising from its internal characteristics may be termed "social vulnerability" (Adger, 1999; Adger and Kelly, 1999). For vulnerability arising purely from the inherent properties of non-human systems or systems for which the term "social" is not appropriate the term "inherent vulnerability" might be used. Social vulnerability is determined by factors such as poverty and inequality, marginalisation, food entitlements, access to insurance, and housing quality (Blaikie et al., 1994; Adger and Kelly, 1999; Cross, 2001). It is social vulnerability that has been the primary focus of field research and vulnerability mapping projects, which are generally concerned with identifying the most vulnerable members of society, and examining variations in vulnerability between or within districts that may experience similar hazards (Downing and Patwardhan, 2003). In this formulation, it is the interaction of hazard with social vulnerability that produces an outcome, generally measured in terms of physical or economic damage or human mortality and morbidity (Brooks and Adger, 2003). Hence social vulnerability may be viewed as one of the determinants of biophysical vulnerability.

The nature of social vulnerability will depend on the nature of the hazard to which the human system in question is exposed: although social vulnerability is not a function of hazard, certain properties of a system will make it more vulnerable to certain types of hazard than to others. For example, quality of housing will be an important determinant of a community's (social) vulnerability to a flood or windstorm, but is less likely to influence its vulnerability to drought. So, although social vulnerability is not a function of hazard, it is, to a certain extent at least, hazard specific – we must still ask the question "vulnerability of who or what to what?" Nonetheless, certain factors such as poverty, inequality, health, access to resources and social status are likely to determine the vulnerability of communities and individuals to a range of different hazards (including non-climate hazards). We may view such factors as "generic" determinants of social vulnerability, and others such as the situation of dwellings in relation to river flood plains or low-lying coastal areas as determinants that are "specific" to particular hazards, in this example, flooding and storm surges.

In summary, biophysical vulnerability is a function of the frequency and severity (or probability of occurrence) of a given type of hazard, while social or inherent vulnerability is not. A hazard may cause no damage if it occurs in an unpopulated area or in a region where human systems are well adapted to cope with it. Where biophysical vulnerability is viewed in terms of outcome (damage resulting from the interaction of hazard with social vulnerability), a system that sustained no net damage from a hazard might be interpreted *post hoc* as being "invulnerable" to that hazard.

In this report the term "social vulnerability" is used in a broad sense to describe all the factors that determine the outcome of a hazard event of a given nature and severity (in other words the nature of the hazard is prescribed and the range of possible outcomes of this specific hazard is a function of social vulnerability). Social vulnerability encompasses all those properties of a system independent of the hazard(s) to which it is exposed that mediate the outcome of a hazard event. These may include environmental variables and measures of exposure. For example the vulnerability of a country to a given hazard occurring over its national territory will be a function of the percentage of the population living in the area affected by the hazard, but also of the extent to which individuals and sub-national systems within this area are exposed to its first-order impacts. Exposure and the state of the environment within a system will be socially determined to a large extent. Exposure will depend on where populations choose to (or are forced to) live, and how they construct their communities and livelihoods. Environmental variables will vary in response to human activity, as populations exploit resources and manage the environment for their benefit in the short or long term.

### *IPCC definitions of vulnerability*

The IPCC Third Assessment Report (TAR) describes vulnerability as

> "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC, 2001, p. 995) (IPCC Def. 1)

Exposure is defined in the same report as "The nature and degree to which a system is exposed to significant climatic variations." Sensitivity is "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)." Adaptive capacity is "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."

The above definition may be compared with that given in Chapter 18 of the TAR, cited from Smit *et al.* (1999), in which vulnerability is described as the "degree to which a system is susceptible to injury, damage, or harm (one part - the problematic or detrimental part - of sensitivity)" (IPCC Def. 2). Sensitivity is in turn described as the "Degree to which a system is affected by or responsive to climate stimuli."

The two IPCC definitions above are very different, and are not consistent. IPCC Def. 1 views the vulnerability of a system as a function of its sensitivity, while Definition 2 views vulnerability as a subset of sensitivity. Vulnerability in IPCC Def. 2 is therefore a subset of one of the determinants of vulnerability as defined in IPCC Def. 1, making the two definitions contradictory, provided they are assumed to be describing the same type of vulnerability.

This contradiction further illustrates the principal conflict over the definition of vulnerability, namely whether vulnerability is determined purely by the internal characteristics of a system, or whether it also depends on the likelihood that a system will encounter a particular hazard, defined in purely physical terms. In other words, whether we use the term "vulnerability" to mean biophysical or social vulnerability. IPCC Def. 1 clearly refers to biophysical vulnerability, with "sensitivity" (or at least "the detrimental part of sensitivity") in IPCC Def. 1 playing an equivalent role to social or inherent vulnerability, while IPCC Def. 2 refers only to social or inherent vulnerability. If we view Def. 1 as a definition of biophysical vulnerability and Def. 2 as a definition of social vulnerability, the conflict is resolved. It is therefore be prudent to avoid using the word "vulnerability" without further explanation, and instead specify to which type of vulnerability we are referring.

### 3.3. Vulnerability and risk

Biophysical vulnerability, as implicitly described in IPCC Def. 1, has much in common with the concept of risk as elaborated in the natural hazards literature. A number of definitions of risk from a variety of different sources are presented in Table 3, along with associated definitions of hazard where these are also given in the source material.

**Table 3. Definitions of risk and hazard. The definitions of Chrichton (1999), Stenchion (1997) and UNDHA (1992) are taken from a similar table in Kelman (2003).**

| Author(s) | Risk definition |
|---|---|
| Smith, 1996 (p5) | Probability x loss (probability of a specific hazard occurrence)<br>*Hazard = potential threat* |
| IPCC, 2001 (p21) | Function of probability and magnitude of different impacts |
| Morgan and Henrion, 1990 (p1)/Random House, 1966 | "Risk involves an 'exposure to a chance injury or loss'" |
| Adams, 1995 (p8) | "a compound measure combining the probability and magnitude of an adverse affect" |
| Jones and Boer, 2003; (also Helm, 1996) | Probability x consequence<br>*Hazard: an event with the potential to cause harm, e.g. tropical cyclones, droughts, floods, or conditions leading to an outbreak of disease-causing organisms.* |
| Downing et al., 2001 | Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period<br>*Hazard: a threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area.* |
| Downing et al., 2001 | Probability of hazard occurrence<br>*Hazard = potential threat to humans and their welfare* |
| Crichton, 1999 | "Risk" is the probability of a loss, and depends on three elements, hazard, vulnerability and exposure." |
| Stenchion, 1997 | "Risk might be defined simply as the probability of occurrence of an undesired event [but might] be better described as the probability of a hazard contributing to a potential disaster…importantly, it involves consideration of vulnerability to the hazard." |
| UNDHA, 1992 | "Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability." |

The definitions in Table 3 are probabilistic in nature, relating either to (i) the probability of occurrence of a hazard that acts to trigger a disaster or series of events with an undesirable outcome, or (ii) the probability of a disaster or outcome, combining the probability of the hazard event with a consideration of the likely consequences of the hazard. The various definitions generally present hazard in terms compatible with the view of hazard elaborated earlier in this paper, although in certain definitions there is some ambiguity as to whether hazard represents a trigger event or the outcome of such an event. Jones and Boer (2003) define hazard explicitly in physical terms. Stenchion (1997) and UNDHA (1992) implicitly define hazard in a similar manner, as an event that might precipitate a disaster but which does not itself constitute a disaster. Where vulnerability is included in the definition of risk, it is viewed as distinct from hazard: it is therefore social vulnerability that is being referred to. Risk defined as a function of hazard and social vulnerability is compatible with risk defined as probability x consequence, and also with risk defined in terms of outcome. The probability of an outcome will depend on the probability of occurrence of a hazard and on the social vulnerability of the exposed system, which will determine the consequence of the hazard.

The ambiguity as to whether it is the probability of occurrence of a hazard, or the probability of a particular outcome that is being referred to is addressed by Sarewitz *et al.* (2003). They define *event risk* as the “risk of occurrence of any particular hazard or extreme event” and *outcome risk* as “the risk of a particular outcome”. They state that outcome risk “integrates both the characteristics of a system and the chance of the occurrence of an event that jointly results in losses.” Sarewitz *et al.* (2003) are referring to social or inherent vulnerability when they “use the word ‘vulnerability’ to describe inherent characteristics of a system that create the potential for harm but are independent of the probabilistic *risk of occurrence* (“event risk”) of any particular hazard or extreme event.”

Outcome risk may therefore be viewed as a function of event risk and inherent or social vulnerability, a formulation broadly consistent with the definitions of risk in Table 3, as long as we acknowledge the ambiguities in the definitions of hazard. This definition of outcome risk is also broadly equivalent to the definition of biophysical vulnerability presented in Section 2.1. Event risk as described by Sarewitz *et al.* (2003) is associated with hazard as defined in physical terms, a view consistent with the concept of hazard as outlined in Section 2.1 and by Jones and Boer (2003).

The principal difference between the natural hazards risk-based approach and the IPCC biophysical vulnerability approach is that risk is generally described in terms of probability, whereas the IPCC and the climate change community in general tend to describe (biophysical) vulnerability simply as a function of certain variables. Nonetheless, the determinants of both biophysical vulnerability and risk are essentially the same - hazard and social vulnerability.

The natural hazards community, which emphasizes risk, and the climate change community, which emphasizes vulnerability, are essentially examining the same processes. However, this has not always been immediately apparent, due to differences in terminology. Both are ultimately interested in the physical hazards that threaten human systems, and in the outcomes of such hazards as mediated by the properties of those systems, described variously in terms of vulnerability, sensitivity, resilience, coping ability and so on. The separation of vulnerability into social and biophysical vulnerability enables us to appreciate the compatibility of the risk-based and vulnerability-based approaches. The concept of biophysical vulnerability addresses the same issues as the concept of risk or, adopting the more precise terminology of Sarewitz *et al*. (2003), outcome risk. Both [outcome] risk and biophysical vulnerability are functions of hazard and social vulnerability, and we may view social vulnerability as equivalent to sensitivity when we are concerned with human systems. The essential equivalence of [outcome] risk and biophysical vulnerability as described above is further illustrated by a report from the International Strategy for Disaster Reduction which separates "risk factors" into two components: "hazard (determines geographical location, intensity and probability)" and "vulnerability/capacities (determines susceptibilities and capacities)" (United Nations, 2002, p.66).

The integration of the risk-based and vulnerability-based approaches is desirable if we are to address the numerous threats that human systems will face in the future as a result of climate variability and change, and also from non-climate hazards. As stated by Kasperson et al. (2001), "What is essential is to assess vulnerability as an integral part of the causal chain of risk and to appreciate that altering vulnerability is one effective risk-management strategy."

### 3.4. Adaptive capacity and the adaptation process

The above discussion has gone some way towards developing a conceptual framework of vulnerability and risk, based on the distinction between social and biophysical vulnerability, and on the equivalence of biophysical vulnerability and risk. This distinction helps us to make sense of the apparently contradictory definitions in the IPCC TAR (IPCC, 2001), by associating hazard with climate variation, sensitivity with social vulnerability, and vulnerability as defined in IPCC Def. 1 with biophysical vulnerability or risk. However, we have not yet addressed the issue of adaptive capacity, and its relationship to social and biophysical vulnerability.

Many definitions of adaptive capacity exist (e.g. IPCC, 2001; Burton et al., 2002; Adger et al., 2003); broadly speaking it may be described as the ability or capacity of a system to modify or change its characteristics or behaviour so as to cope better with existing or anticipated external stresses. We may view reductions in social vulnerability as arising from the realization of adaptive capacity as adaptation. The term adaptation is used here to mean *adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stresses*. Given constant levels of hazard over time, adaptation will allow a system to reduce the risk associated with these hazards by reducing its social vulnerability. Faced with increased hazard, a system may maintain current levels of risk through such adaptation; reductions in risk in the face of increased hazard will require a greater adaptation effort. If hazards increase dramatically in frequency or severity, a human system may face greater risk despite reduction in social vulnerability achieved through the implementation of adaptation strategies.

Societies have inherent capacities to adapt to climate change. These capacities are bound up in the ability of societies to act collectively. Decisions on adaptation are made by individuals, groups within society, organizations and governments on behalf of society. But all decisions privilege one set of interests over another and create winners and losers. Examining the social dynamics and outcomes of adaptation moves beyond simply accounting for the economic costs and benefits of adaptation. One element of this project has been to explore the nature of these society-environment interactions, particularly the role of social institutions and social capital in adaptation processes. By social capital here we mean a set of networks, agreements, and flows of information. At its core the concept encapsulates 'features of social organisation such as trust, norms and networks that can improve the efficiency of society by facilitating co-ordinated actions' (Putnam et al., 1993, p. 167). Some social capital may emerge as a result of economic transactions and activities, but many aspects of social capital do not. Social capital provides an explanation for how individuals use their relationships to other actors in societies for their own and for collective good, both in material terms and for wider spiritual and social benefits.

The nature of the relationships between state and civil society and the relative role of each in adaptation has been explored in a series of conceptual and empirical papers (Adger, 2001, 2003, 2004; Tomkins and Adger 2003).

The conceptual work argues that current frameworks promoted by, for example, the IPCC, fail to point out the key relationship between civil society and government. Often distinctions are drawn between planned adaptation by governments on behalf of society on the one hand and autonomous adaptation by individuals on the other (summarized in Smit et al., 2001). But this distinction obfuscates the role of the state in promoting development paths that cause institutional and technological lock-in and indeed often promote unsustainable practices that reduce the ability to adapt in the long run.

Although the capacity of individuals to adapt to climate change is a function of their access to resources, the adaptive capacity of societies depends on the ability to act collectively in the face of the threats posed by climate variability and change. Thus adaptive capacity, as an element of overall vulnerability of a society, can be illuminated through examining the institutions for resource management and their effectiveness, efficiency and legitimacy. Social capital is made up of the networks and relationships between individuals and social groups that facilitate economic well-being and security. Indeed previous research in coastal environments demonstrates that social capital is an important element for coping with climate variability and hazard in the present day. In the Caribbean, for example, Tompkins and Agder (2003) show that communities find strategies to manage risks through strategic and local networks and interactions. Many aspects of adaptive capacity are, in effect, latent in the networks and information of those likely to be affected. This suggests, though has yet to be tested, that some groups within society may be less at risk than modelling studies portray because of this latent ability to cope in times of stress.

The direct effect of adaptation is to reduce social vulnerability. Whether or not this translates into a reduction in biophysical vulnerability or risk will depend on the evolution of hazard. In the case of anthropogenic greenhouse warming and any associated changes in climate, the only certain way of reducing risk is therefore via a combination of adaptation and mitigation strategies, the purpose of the latter being to reduce hazards. In the following discussion on adaptive capacity and adaptation, the term vulnerability will therefore be used to refer to *social vulnerability*, unless otherwise stated. Where the text refers to reductions in vulnerability as a result of adaptation, this should be interpreted as social vulnerability, and by extension to biophysical vulnerability *only under conditions of constant hazard*.

In IPCC Def. 1, biophysical vulnerability is a function of adaptive capacity, which is viewed as distinct from sensitivity, which we may view in turn as being broadly equivalent to social vulnerability. Given the broad equivalence of biophysical vulnerability and risk (Section 3), IPCC Def. 1 suggests that if a system has a high capacity to adapt, it is less "at risk". However, the adaptation process and the nature of the relationship between the vulnerability and adaptive capacity of a system will be mediated by the nature of the hazard(s) faced by the system.

Three broad categories of hazard may be identified:

Category 1: Discrete recurrent hazards, as in the case of transient phenomena such as storms, droughts and extreme rainfall events.
Category 2: Continuous hazards, for example increases in mean temperatures or decreases in mean rainfall occurring over many years or decades (such as anthropogenic greenhouse warming or desiccation such as that experienced in the Sahel over the final decades of the 20th century (Hulme, 1996; Adger and Brooks, 2003).
Category 3: Discrete singular hazards, for example shifts in climatic regimes associated with changes in ocean circulation; the palaeoclimatic record provides many examples of abrupt climate change events associated with the onset of new climatic conditions that prevailed for centuries or millennia (Roberts, 1998; Cullen *et al*., 2000; Adger and Brooks, 2003).

Adaptation does not occur instantaneously; a system requires time to realise its adaptive capacity as adaptation. Adaptive capacity represents *potential* rather than actual adaptation. A high level of adaptive capacity therefore only reduces a system's vulnerability to hazards occurring in the future (allowing the system time to adapt in an anticipatory manner) or to hazards that involve slow change over relatively long periods, to which the system can adapt reactively. In other words, adaptive capacity is a determinant of vulnerability to Category 2 hazards and *anticipated future* Category 1 and

3 hazards. The damage to a system resulting from a discrete hazard event such as a storm or flood occurring tomorrow would not be a function of the system's ability to pursue future adaptation strategies – it is existing adaptations resulting from the past realization of adaptive capacity that determine current levels of vulnerability. The likelihood of a system adapting responsively to (as opposed to coping with) a sudden short-lived event such as a hurricane is negligible.

However, a system's vulnerability to more gradual, longer-term change will be a function of it's ability to adapt incrementally and responsively, and its vulnerability to discrete hazards occurring in the future will be a function of its ability to anticipate and pre-empt those hazards via appropriate planned adaptation strategies. The rate at which *risk* (or biophysical vulnerability) associated with a particular type of hazard is reduced (or increased) will depend on the timescales associated with the implementation of adaptation measures (i.e. the realisation of adaptive capacity as adaptation) and also on the timescales associated with the evolution or occurrence of the hazard in question (in the case of global-scale anthropogenic climate change the latter will be influenced by global development pathways and the extent to which mitigation is pursued). In other words, we must ask ourselves whether a system is likely to implement the necessary adaptation measures in the time available to it in order to reduce risk to a subjectively defined acceptable level.

For example, global mean sea level is expected to rise by a maximum of around 45 cm by 2050 (Sear et al., 2001). While many countries are *currently* vulnerable to a 45 cm sea level rise (assuming no further adaptation were to occur over the next half-century), for this particular threat we are concerned with future vulnerability, perhaps assessed in terms of the ability to cope with a given annual or decadal rise in sea levels up until the middle of the twenty first century. The risk posed to a country or coastal zone by sea level rise will depend on the rate at which it occurs, the system or region's existing vulnerability, and the rate at which the system can adapt (c.f. IPCC Def. 1). Existing (social) vulnerability is important as it constitutes the "baseline" from which any reduction of vulnerability to "acceptable" levels via adaptation must take place. Risk assessments for sea level rise typically examine the risk associated with a given increase in sea level assuming current levels of social vulnerability, perhaps modulated by changes in population density (Nicholls et al., 1999; Parry et al., 2001). A comprehensive assessment of risk would examine the likelihood of a specific rate of sea level rise over a given period (hazard), and the potential or likely evolution of a system's vulnerability to that rise based on *current vulnerability* and the *potential or likely amount of adaptation* over that period.

### 3.5. Adaptive capacity and current and future vulnerability

Another way of addressing the important issue of timescale is to distinguish between current and future vulnerability. Current vulnerability, determined by past adaptation and the current availability of coping options, provides a baseline from which a system's future vulnerability will evolve. This evolution will be mediated by the system's adaptive capacity and the extent to which this capacity is realised as adaptation. At any given time, we may view a system as exhibiting a certain degree of vulnerability to a specified hazard, and as having a certain capacity or potential to adapt so as to reduce its vulnerability to that hazard within any given time frame, constrained or modulated by a range of external factors.

If the hazard in question is a particular type of discrete, transient, extreme climatic event, we may speak in terms of the system's *current vulnerability*, a "snapshot" which determines the extent to which it would be damaged if the event in question occurred immediately. We may also speak of the system's *potential vulnerability*, or the vulnerability it would have at a specified point in the future to a specific hazard as a result of realizing all its current adaptive capacity through anticipatory adaptation.

If we assume that adaptation is a function of adaptive capacity only, in other words that all a system's adaptive capacity is realised as adaptation, a system's *actual vulnerability* will vary with time as its adaptive capacity fluctuates in response to changes in environmental, political, social and economic. Adaptive capacity may also be reduced by the impacts of the very hazards that a system must adapt to.

The above allows vulnerability and adaptation studies to be put on a more quantitative footing where this is deemed to be desirable, for example in terms of integrated assessments involving modelling components, or where quantification is useful in order to assess the success or failure of adaptation strategies. Differences in social vulnerability resulting from different development pathways might be assessed by running models with a suite of different socio-economic scenarios under conditions of constant hazard. Outcomes measured in terms of mortality and morbidity or economic damage could then be used to assess the impacts of different modes of development on social vulnerability (assuming each socio-economic scenario is associated with the same hazard(s)). Of course vulnerability is also influenced by hazard events through a variety of feedback processes such as the destruction of resources and the exacerbation of poverty and inequality by climate-related disasters. Such processes should be accounted for in modelling studies if they are to be of any value.

### 3.6. Generic and specific vulnerability and adaptive capacity

We have seen above how the adaptation process is determined to a large extent by the nature of the hazard to which a system or population must adapt. Certain factors will make a system particularly vulnerable to specific types of hazard, while other factors might mean that a system has a high capacity to adapt to some hazards but not others. For example, plentiful groundwater reserves will enable a country to adapt to an increased frequency of drought by expanding irrigation. A weak regulatory environment and the existence of informal markets might also enable people to adapt to drought through crop and income diversification. However, none of these factors will directly reduce people's vulnerability to, or help them adapt to, floods or windstorms. We may therefore describe such factors as representing "specific" vulnerability and adaptive capacity, specific in this example to drought.

However, other factors will act to influence vulnerability and the capacity of people to adapt to a range of hazards. Poverty might prevent people from investing in the farm inputs necessary for diversification and the means to transport their produce to market, and is also likely to be associated with poor quality housing that is easily damaged by floods or storms. High levels of inequality are likely to result in the formation of highly vulnerable groups that are financially and socially marginalised, who lack the financial resources for adaptation and who may be forced to settle in exposed areas such as flood plains, unstable hill slopes or regions of marginal rainfall. We might refer to factors such as poverty and inequality as representing "generic" vulnerability and adaptive capacity, i.e. as factors that determine vulnerability and the capacity to adapt to a wide range of hazards.

If we were performing a national assessment for a particular country we might proceed first by assessing that country's generic vulnerability and adaptive capacity in order to identify needs and options for increasing the country's ability to cope with a wide range of hazards. We would then identify the principal existing hazards that already have significant negative impacts on a regular basis, and potential future hazards that represent the most likely threats to human welfare and economic development. Existing hazards are easily identified from the recent historical record, while potential future hazards might be identified through modelling studies, historical or palaeoclimatic analogy, analysis of existing trends and a consideration of physical principles. Once such hazards had been identified, assessments of specific vulnerability and adaptive capacity could be carried out for each hazard in turn.

The identification of priority hazards and of vulnerability to them is essentially an exercise in the assessment of outcome risk. Within the context of the framework outlined above we may view the outcome risk associated with a particular type of hazard over a given period of time as a function of event risk and the social/inherent vulnerability of the exposed systems and populations. The way in which event risk is defined will depend on the nature of the hazard with which we are concerned. Event risk might refer to the probability of occurrence of a single unique or long return-period event, or to the actual or project frequency of occurrence of a recurring hazard. We might be interested only in the occurrence of events whose severity exceeds a given physically defined threshold, or we might wish to define event risk in terms of the frequency of occurrence of a particular type of hazard combined with some measure of intensity, perhaps based on mean or peak severity.

### 3.7. Implications for national-level indicators

The conceptual framework outlined above provides a context for studies of national-level vulnerability to climate change. Clearly the *systems* of interest are individual nation states, and the *hazard* to which they are exposed is global climate change. In reality, global climate change will manifest itself through the types of hazard described in Section 3.6. above. When we talk of the vulnerability of a nation to global climate change we are therefore talking about the vulnerability of that nation to a variety of different hazards associated with climate change. Assessments of vulnerability and adaptive capacity for individual countries will be most useful when they consist of assessments of generic vulnerability and adaptive capacity, followed by assessments of vulnerability and capacity to adapt to the specific hazards that pose the greatest threat to human welfare and national economic development for a particular country. Such assessments may be broken down by sector, region or population group. The importance of a particular hazard will vary across sectors, regions and groups, for example varying with resource requirements, livelihoods and geographic location.

Different countries are subject to different existing hazards, and the manifestations of climate change will also vary across the globe. Recognition of the geographic variation of hazards associated with current climate variability and future climate change must be the staring point of any attempt to compare vulnerability and capacity to adapt to climate change across countries. The conceptual framework outlined above can help us to design a number of approaches to the assessment of vulnerability and adaptive capacity, through a consideration of the relationship:

**Biophysical vulnerability = f (hazard, social/inherent vulnerability)**.

Biophysical vulnerability in this expression is broadly equivalent to outcome risk as described above, with the caveat that the former is often viewed in terms of damage while the latter is more likely to be viewed in terms of probabilities. For the sake of brevity, the terms risk and vulnerability will be used from here on to refer to outcome risk and social or inherent vulnerability respectively. Hazard might be described in terms of event risk or probability, or based on the observed or projected frequency of a given type of hazard event, perhaps scaled by a measure of severity based on mean or peak intensity.

Risk hazard and vulnerability may all be represented by indicators. The ultimate purpose of any assessment of risk, hazard or vulnerability must surely be to reduce the outcome risk associated with a particular hazard or range of hazards. At the sub-national level, and even at the national level, we might perform a comprehensive risk assessment based on separate assessments of hazard and social vulnerability. Where a system, region or population group exhibits high vulnerability and is faced with a high level of hazard, risk will be high. On a geographic basis, maps of hazard and vulnerability may be produced to identify risk “hot spots”. Separate maps might be produced for different hazards, and for the vulnerabilities of systems to these hazards. Overall risk, hazard and vulnerability scores might be calculated by aggregating the results relating to individual hazards.

Such an approach is not practical for comparisons across large numbers of countries, unless it is performed as part of individual national assessments coordinated at the international level to ensure that risk, hazard and vulnerability are comprehensively assessed and aggregated to produce national scores following a consistent methodology that results in these scores being comparable across countries. While such an exercise is possible in principle within the context existing national assessments of vulnerability and National Adaptation Plans of Action, it has not been undertaken.

Any comparative study of national-level risk, hazard or vulnerability must at present make use of publicly available data sets in which a large number of countries are represented by comparable data. A number of datasets exist that relate to socio-economic and political conditions, the state of the environment, and the outcomes of disasters (including climate-related "natural" disasters). Climatological and meteorological data relating to climate hazards are also plentiful, although using these to construct national-level hazard indices is problematic because of the geographical variation in the nature of climate hazards.

The potential for using existing data sets to construct indices of risk, hazard and vulnerability is discussed below, starting with the most problematic variable: hazard.

### 3.8. Indicators of climate hazard

For a particular type of recurrent climatic or meteorological phenomenon, it is in principle possible to construct national-level indicators of existing hazard from data relating to the frequency and severity of the type of event in question. For example, we might construct a hurricane index based on the historical frequency of hurricanes that made landfall in a particular country, scaled by the inhabited area of that country in order to give a greater weight to countries with a small area such as small island states, where a single event can have a serious impact on national well-being. Countries which did not experience hurricanes would score zero on this particular index.

For a more complex and long-lasting hazard such as drought, an index might be based on the historical frequency of drought, the average area affected, and the average or maximum duration of historical droughts. We would then have to ask ourselves what constitutes a drought, and whether droughts in one climatic regime (for example semi-arid regions such as the Sahel) were comparable with droughts in another (such as western Europe). A better measure of drought-related hazard might be based on average annual rainfall, interannual variability and seasonality.

The above examples both involve the use of historical data to construct hazard indices, that relate to existing climate variability. The situation becomes much more problematic if we wish to construct hazard indices relating to future climate change and variability. Such an undertaking would involve estimates of future event frequency and the likelihood of occurrence of singular climate events based largely on modelling studies, and the uncertainties in such estimates are likely to be significant.

A "climate change hazard index" would have to aggregate hazards arising from changes in climate variability, shifts in climatic regimes and the occurrence of singular climate events. It would need to take account of the probability of occurrence of particular events within a given period, and would therefore be timescale dependent. Furthermore, it would need to address the issue of whether or not extreme events that have occurred in the recent past (such as floods and droughts) are the result of climate change or a manifestation of existing climate variability. These questions of attribution and probabilistic estimates of the likelihood of future climate events are extremely problematic and controversial. In practice any such index would most likely be a composite index of hazards arising from climate variability and change. Indeed, it might be argued that the distinction between climate change and climate variability is artificial, and that we should instead refer to climate variability on different time scales, driven by a variety of processes including human modification of the atmosphere.

Even if indices for individual countries are constructed by aggregating information relating to a range of existing and potential hazards, the problem of comparing scores across countries remains. How can we compare drought hazards with hurricane hazards in order to assess whether the hazards associated with climate variability and change are greater for a country in semi-arid Africa than for a small island state? Is such an exercise meaningful or useful? At the global level, developing standardised, aggregated hazard indices for cross-country comparisons is likely to be of limited value even if such an exercise is feasible.

The only means of managing climate hazards (as opposed to their impacts) is through mitigation or large-scale physical engineering of the Earth's surface in order to influence climate feedback processes. Mitigation cannot reverse climate changes to which we are committed as a result of past greenhouse gas emissions, or ameliorate the negative aspects of natural climate variability. Our knowledge of climate feedbacks and our ability to undertake what we might term planetary engineering are currently inadequate to manage climate variability. It has been suggested that any mitigative actions we take today will have little or no impact on the evolution of the global climate for several decades (Corfee-Morlot and Höhne, 2003), the nature of which will be determined by a combination of past emissions, climate sensitivity and natural climate variability. In the near to medium term, climate risk must therefore be managed by adaptation strategies and measures designed to reduce vulnerability.

While it is important to have an appreciation of the nature and geographical variation of climate hazards in order to manage the adaptation process, we should concern ourselves predominantly with assessing risk and vulnerability. We must ensure that countries are able to cope with existing hazards and those anticipated in the near term, in order that damage from such hazards does not hold back development efforts and exacerbate existing vulnerability, undermining the foundation on which adaptation to future climate change must be based. Many countries already cope poorly with climate hazards, and it is likely that in the near term climate change will manifest itself at the local and regional level in terms of changes in the frequency, severity and timing of the kinds of hazard familiar from historical records. Reducing vulnerability to existing hazards is therefore the most desirable starting point for reducing the risks associated with climate change. In some countries such an approach is vital and urgent in order to address current developmental issues. In terms of identifying priorities for adaptation assistance, the management of adaptation in the near future may be based on assessments employing indicators of current risk and vulnerability, based on recent historical and current data.

### 3.9. Outcome-based indicators of climate risk

Risk as described in the above discussion is an aggregate measure of hazard and vulnerability. Hazard and vulnerability interact to determine the outcomes of climatic or meteorological events, and we can use measures of outcome as indicators of risk associated with recent and current climatic variability. For example, we might wish to examine mortality risk at the national level associated with a given type of hazard or range of hazards for a given historical period. Such an assessment can be based on the numbers of people killed over that period as a result of the occurrence of the hazard(s) in question. We can also examine the risk of displacement and wider disruption by using data relating to people made homeless and otherwise affected by hazard events. Historical economic risk can be assessed by examining the economic costs of the impacts of hazard events.

For any given type of hazard, we cannot talk in terms of absolute risk, but only in terms of the risk associated with that hazard on a particular timescale. For example, if we assess risk based on the number of people killed by a particular type of hazard over a period of several years, we are examining risk associated with interannual climatic variability (assuming the period does not contain any rare extreme events that usually recur on much longer periods), modulated by the vulnerability of the exposed populations. In order to assess risk from events with return periods measured in decades or centuries we would have to extend our analysis further into the past (assuming we were using historical data). However, vulnerability evolves with time, and as we extend our analysis further back in time the vulnerability component will become less representative of today’s conditions. Where the purpose of risk assessment is to facilitate intervention to reduce current vulnerability, assessments using outcome-based indicators or risk must strike a balance between capturing the elements of climate variability that constitute the most prevalent hazards, and constraining the period of analysis so that the vulnerability component of risk is broadly representative of current conditions.

Given the high frequency of climate-related disasters throughout much of the world, outcome-based risk assessments may be performed over relatively short periods and still capture the types of hazard that regularly cause significant damage in many countries. If, as some authors suggest (Vellinga and Mills, 2001), certain hazards are already becoming more frequent and severe, risk assessments based on quite short recent historical data may well be more representative of near-future risk than assessments carried out over longer historical periods. By examining the numbers of people killed and otherwise affected over decadal periods we can assess the risk associated with short-term (i.e. interannual or sub-decadal scale) climate variability during periods characterised by different levels of vulnerability. Where socio-economic and political systems have been relatively stable throughout the final years of the twentieth century and the first years of the twenty first, we might use outcome-based measures of risk over the 1990s as a proxy for current and near-future risk associated with climate variability. Given the driving mechanisms of hazard and vulnerability, where current risk associated with sub-decadal scale variability is high, risk associated with climate change in the near future is also likely to be high for two reasons: (i) in the near to medium term, climate change is most likely to manifest itself through changes in the frequency and severity of existing hazards and (ii) high levels of vulnerability coupled with increases in hazard event risk are a recipe for significant negative outcomes which are likely to further exacerbate vulnerability.

### 3.10. Predictive indicators of vulnerability and adaptive capacity

Outcome based indicators of risk by definition represent the consequences of the interaction of hazard and vulnerability, and can tell us very little about the underlying structural causes of vulnerability. Interventions to reduce risk at the country level therefore require an analysis of the various factors that determine vulnerability and adaptive capacity at and below the national level. The use of indicators to represent these factors allows us to identify priority areas for the reduction of vulnerability and the enhancing of adaptive capacity.

For the purpose of inter-country comparisons, we require generic indicators applicable to all countries. Such indicators will therefore capture the generic vulnerability and adaptive capacity of countries to a range of hazards, but will not include measures of specific adaptive capacity except perhaps some broad measures of vulnerability to particularly important and widespread hazards such as flooding and drought. For example, the percentage of the national population living on flood plains or in low-lying coastal areas may reasonably be included as an indicator of "generic" vulnerability, as floods, storm surges and coastal erosion are major aspects of climate risk affecting many countries. As sea level rise represents one of the principal problems associated with climate change, it may reasonably be argued that countries with low percentages of their populations living in regions prone to flooding and storm surges will be less vulnerable to climate change than those with high percentages of their populations in such areas. Because of their global importance, spatial extent and range of impacts, exposure to drought and flood hazards represents an important element of vulnerability, and these major hazards may be addressed in assessments of generic vulnerability and adaptive capacity. Flood-related indicators may be complemented by drought-related indicators such as the percentage of the population immediately dependent on agriculture, or living in remote rural areas without access to clean water.

The flood and drought indicators suggested above are representative of exposure, and are relevant to all countries; where countries are landlocked national scores relating to vulnerability to coastal climate hazards will simply be zero. These low scores may be offset by high scores for vulnerability to drought. Exposure is different from hazard: a country or region may regularly experience flood hazards but the exposure of its population to these hazards may be limited by situating settlements away from flood plains and low-lying coastal areas. In the case of drought, low exposure might be a result of a lack of dependence on rainfall sensitive livelihoods such as rain-fed agriculture.

Indicators of specific vulnerability and adaptive capacity will relate to particular types of hazard as they occur in specific local contexts. For example, where tropical storms represent the principal climate hazard, one measure of vulnerability might be the availability of storm shelters. In agrarian societies, vulnerability and adaptive capacity might depend on local (or world) market prices of particular crops - higher prices will allow producers to buy foodstuffs and invest in adaptation measures such as irrigation or diversification. Conversely, high food prices will increase the vulnerability of the very poor - the nature of vulnerability will therefore depend on the distribution of wealth and price-based indicators will have to be constructed with careful consideration of socio-economic conditions. Obviously we cannot use places in storm shelters per 1000 people, or the price of a particular crop, as an indicator of vulnerability or adaptive capacity that is appropriate for all countries.

National level indicators will be based on generic measures of wealth, inequality, food availability, health status, education, physical and institutional infrastructure, access to natural resources and technology, and geographical and environmental factors. The determinants of generic vulnerability and adaptive capacity will be similar in many cases, although the distinction between them will be clarified through a consideration of current and potential future vulnerability. Indicators of adaptive capacity will represent factors that do not determine current vulnerability, but that enable a society to pursue adaptation options in the future. An example is investment in scientific research and development; a sound research base will not necessarily reduce the vulnerability of those most at risk, but it will provide a foundation on which research into future climate hazards and appropriate adaptation strategies may be based. Groundwater reserves will not make a country less vulnerable to drought unless those reserves are exploited to augment water resources based on rainfall and available surface water. Such exploitation may require access to particular types of technology. Investment in research and development may also enable a country to develop desalination technology to augment terrestrial water reserves.

## 4. CONSTRCUTION OF OUTCOME-BASED INDICATORS OR RISK

### 4.1. The EM-DAT dataset

Indicators of historical outcome risk on decadal time scales were constructed from the Emergency Events Database (EM-DAT), developed by the US Office of Foreign Disaster Assistance (OFDA) and the Centre for Research into the Epidemiology of Disasters (CRED) at the Université Catholique de Louvain in Brussels, Belgium (http://www.cred.be/emdat). EM-DAT data nominally cover all countries over the entire twentieth century. However, data are sparse for many countries and regions prior to about 1970. The database contains entries under a number of different categories for individual natural disasters (a version including technological disasters is also available). Along with entries describing the type of disaster, its date and location, are entries for numbers killed, injured, made homeless and otherwise affected (i.e. otherwise requiring immediate assistance). There is also an entry for 'total affected', including those injured, made homeless and otherwise affected. Other categories describe economic damage in US Dollars, Euros and local currency, value on appropriate disaster scale, data sources, whether there was an OFDA response, and general comments. An event qualifies for inclusion in EM-DAT if it is associated with 10 or more people reported killed, 100 or more people affected, a call for international assistance, or the declaration of a state of emergency.

### 4.2. Pre-processing of the EM-DAT data

In order to use the EM-DAT data for an analysis of climate risk, the dataset was processed in order to remove entries relating to disasters without a climatic component. Data representing earthquakes and volcanic eruptions were removed, and the remaining categories were examined in order to remove events that are not climate-related. The disaster types that are climatic in nature or which may include a climatic component fall into the following categories: (i) drought, (ii) epidemic, (iii) extreme temperature, (iv) famine, (v) flood, (vi) insect infestation, (vii) slide, (viii) wave and surge, (ix) wild fire, and (x) windstorm.

The significance for studies of climate risk of many of the events listed above is somewhat ambiguous. For example, famines may be caused principally by persistent drought, but are often multi-factorial and may be precipitated as much by conflict, mismanagement or social upheaval as by climatic factors. Epidemics may result from floods, or weakened immunity arising from malnutrition as a result of drought and famine, but may also arise from population movements and changes in social behaviour. Waves and surges include tsunamis, which are associated with earthquakes. Slides may occur as a result of human activity. Consequently, it was necessary to remove from the dataset events that are unlikely to be related to climatic variability or change. For categories with few entries this was straightforward and entailed examining the notes for each event: all tsunami events were removed from the wave and surge category as these are associated with earthquakes, and six slide events were removed; these were associated with volcanic eruptions, mining, a dam site collapse and a 'leaking water tank'.

Most epidemic data were retained, as infection rates for the majority of diseases represented exhibit strong seasonal variation and are strongly influenced by the ambient climatic environment. Only anthrax, rabies and smallpox are removed; anthrax and rabies do not exhibit seasonal variation and smallpox has been eradicated globally. It is recognised that epidemics are complex phenomena that may be driven by non-climatic factors, and their inclusion here is likely to be controversial. However, epidemics account for a small percentage of the global disaster burden over the periods assessed (particularly the last three decades of the twentieth century), and their inclusion does not affect the results of the analysis significantly.

The classification and definition of famines is particularly problematic due to the difficulty of decoupling climatic influences, particularly drought, from socio-economic causes of such events. At its essence, famine is a socio-economic process of extreme disruption to livelihoods for significant numbers of people, sometimes (but not necessarily) resulting in mass starvation, but also in migration, selling of assets and the breakdown of traditional social bonds. There are numerous definitions of famine, due in part to the fact that there are numerous causes of famine. The proximate causes of famine may include natural hazards such as extreme weather events (principally drought and floods), earthquakes, or biological pests, but more often the proximate causes are wars or other large-scale social disruptions. Underlying the proximate causes are socio-economic relationships such as the distribution and level of income and poverty. One of the difficulties in defining famine, and hence vulnerability to famine, is in delineating famine conditions from normal conditions of poverty. Hence famine is often conceived as a continuum at the extreme of poverty and starvation (see Sen, 1981; Devereux, 1993).

Some famines are so manifestly the result of the breakdown of production, distribution and entitlement structures that it is tempting to ignore them altogether within the global data on natural disasters. While such famines may not be caused predominantly by drought, it may be drought that acts as the trigger that causes social disruption to turn into famine. For example, the Ethiopian famine of 1984 was largely a result of civil conflict and abandonment of land, exacerbated by social policies, but the final trigger for the famine was a failure in rainfall (Defegu, 1987). Certainly this particular event was not solely the result of drought, but it would probably not have occurred without the drought - in this case drought was a necessary but not sufficient condition for the onset of famine. While it may be tempting to discard such cases as being extreme and unrepresentative, they are crucial in an assessment of risk as they represent cases of disasters caused by extreme vulnerability resulting from changes in socio-economic circumstances. While they may be singular in nature and caused by human agency through conflict or large-scale and inappropriate social engineering, they are instructive and meaningful as they represent a breakdown in a society’s coping ability.

Two major historical famine events, notorious in 20th century history, illustrate the problems of attributing climate or weather causality. These are the events in eastern India in 1943-1944 and in China in 1957-61.

In the EM-DAT database, only one Indian famine is recorded, in 1991. Other famine events, including that closest to the Bengal 1943 events are recorded under the category of ‘drought’ recording 1.5 million deaths. The Bengal famine of 1943-44 was the result of a combination of non-climate factors including ‘a long-term deterioration in the economic conditions of the poor’ and a cessation of rice imports from Burma due to Japanese occupation during the Second World War (Maharatna, 1996, p. 129). In the analysis of Sen (1981; 1993), the so-called Great Bengal Famine occurred at a period when social differentiation, speculation and hoarding drove up food prices faster than real wages, and caused a rural famine. The effective demand of rural people (their exchange entitlements) had effectively collapsed and no social security system (transfer entitlements) was in place (see also Sen, 1993; Nolan, 1993).

Analysis of the Chinese famine that followed Mao's 'Great Leap Forward' tends not to mention climatic factors as being important causes. Although this episode is still controversial, there is some consensus that the famine was effectively the result of industrialisation and 'modernisation' that took place at the expense of food production for indigenous consumption. In effect it had little to do with climatic factors but rather was a result of government policies in both the agricultural and other sectors. Recalling her childhood, Jung Chang, in her autobiography refers to so-called unprecedented natural calamities that the Chinese government emphasised as being responsible for food shortages:

> 'China is a vast country, and bad weather causes food shortages somewhere every year. No one but the highest leaders had access to nationwide information about the weather. In fact, given the immobility of the population, few knew what happened in the next region, or even the next mountain. Many thought then, and still think today, that the famine was caused by natural disasters. I have no full picture, but of all the people I have talked to from different parts of China, few knew of natural calamities in their regions. They only have stories to tell about deaths from starvation' (Chang, 1993, p.311).

There are no entries for China under the categories 'drought' or 'famine' for the period 1957-61. However, there is an entry under the category 'flood' for 1959, associated with 2 million deaths. Given that there was widespread official denial of the existence of this particular famine, and a refusal to acknowledge its socio-economic causes with the blame placed on natural causes where deaths were acknowledged, it is likely that these figures are derived from official sources that wrongly describe both the magnitude and nature of this disaster (it is believed that up to 30 million people died between 1957 and 1961).

The 1942 Indian 'drought' entry and the 1959 Chinese 'flood' entry are thus removed from our dataset; while the principal period of interest is 1970-2000, earlier decades are of interest in terms of trends related to changes in recording practices and other non-climatic factors.

Three other famines have also been removed: these are identified within the database notes as being associated with non-climatic factors, and the notes are reproduced below:

- Togo, 1992: Poor harvest and internal distribution problems due to political disturbances resulted in critical food shortages in all regions.
- Armenia, 1992: Fuel and food shortages from disruptions of supplies due to unrest, armed conflict and economic blockade, hundreds thousands affected. The government declared on 7 December the country in a state of national disaster an appeal for international community to provide assistance, 1.3 million children at risk from hunger, cold, inadequate shelter and infectious diseases.

- Comoros, 1975: Major economic problems, food shortages and risk of famine.

Most famines are associated explicitly in the database notes with droughts or floods, although a small but significant number do not have any associated descriptions. The latter are retained; events with no associated notes are a possible source of error in the data, although famines that are not at least partly associated with climatic factors appear to be the exception rather than the rule, suggesting that greater accuracy will be achieved by including rather than rejecting such ‘anonymous’ events.

The data of most interest from the point of view of vulnerability assessment are those relating to mortality and the numbers of people adversely affected by climate-related events. While economic damage is also an important indicator of the severity of the impacts of climate-related disasters, data relating to the cost of disasters are relatively sparse and are also difficult to estimate. Economic damage can certainly cause significant hardship at the societal, household and individual level, but the low density of economic data in EM-DAT is such that economic indices are unlikely to be representative or particularly useful. Furthermore, such an index would be likely to emphasise the impacts of extreme events on wealthy nations, where the concentration of capital assets increases the likelihood of quantifiable and high economic losses. Risk indices were therefore based on measures of direct, short-term societal disruption due to displacement, trauma and death, rather than in terms of loss of capital. From the subset of climate-related disasters, data representing people killed and people affected were extracted for each recorded event, along with the country and year in which the event occurred.

### 4.3 Coverage and reliability of EM-DAT, and trends in the dataset

Global and regional trends in the frequency of climate-related disasters, and in the numbers of people killed and affected by these disasters, were examined in order to assess changes in data coverage over time. The broad trend in recorded disaster occurrence is one of increasing frequency in the latter half of the twentieth century (Figure 1), likely to be the result of several factors such as increases and improvements in reporting, population growth and increased population in areas subject to climate-related disasters (Berz, 1997). Increases in capital assets are also likely to have led to a greater frequency of reporting as economic damage for any given event type increases. Climate change may also have played a part in increasing the frequency of disasters (Augusti *et al.*, 2001; Frich *et al.*, 2002). Nonetheless, there is considerable variation between years in the recorded frequency and impact of climate-related disasters, particularly when the data are disaggregated in terms of disaster type and geographical region, suggesting that variations in recorded event frequency are not simply the result of the changes in demographic factors and reporting, and that climatic variability on a variety of timescales plays an important role in influencing the data..

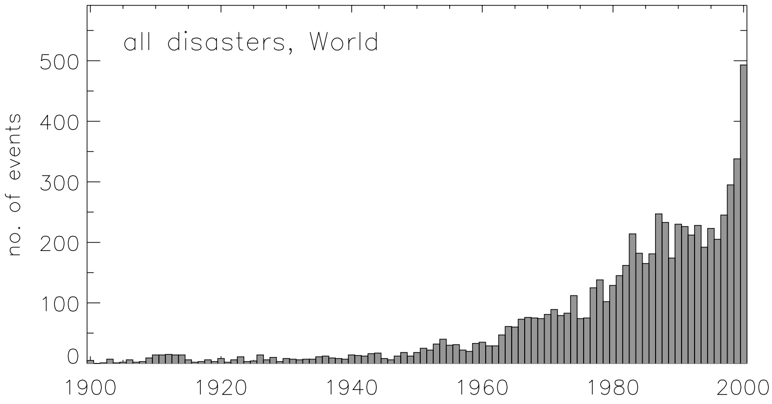


**Figure 1. Annual global frequency of recorded climate-related disasters for all disaster types.**

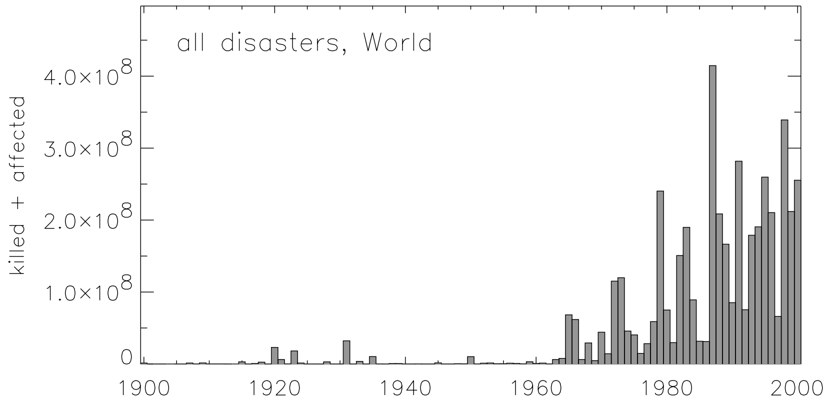


**Figure 2. Annual sums of numbers killed and affected by all climate-related disasters worldwide.**

Aggregated numbers of those killed and affected by all disaster types increase dramatically after 1960, but exhibit considerable interannual variability (Figure 2). There is an extremely steep downward trend in the ratio of killed to affected over the entire twentieth century (Figure 3). A number of years prior to 1935 are associated with very large numbers killed (between one and four million); after this period there are several notable peaks but no long-term trends (Figure 4). Together these results suggest that numbers killed by high-mortality disasters have been recorded in a relatively constant fashion throughout the twentieth century (with numbers killed generally being greater prior to 1950), while more careful analysis involving assessments of the numbers otherwise affected is a relatively recent innovation. These are general observations, and there is likely to be considerable variation in recording practices between different countries and event types. However, similar results are obtained from regional and global analyses of specific disaster types.

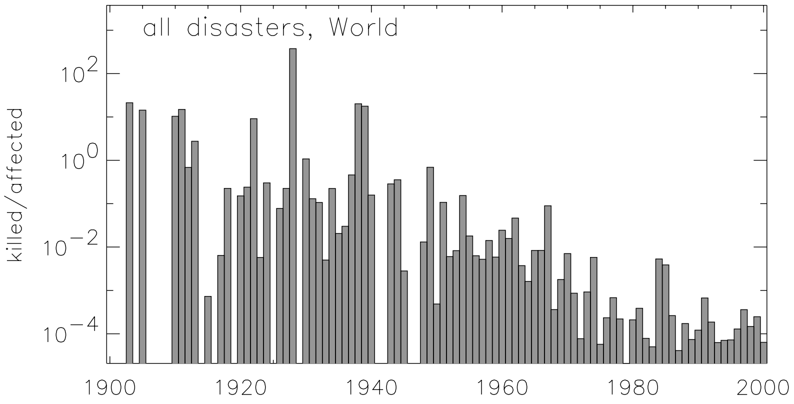


**Figure 3. Annual ratios of worldwide total killed to worldwide total affected for all climate-related disaster types. Note logarithmic scale on vertical axis.**

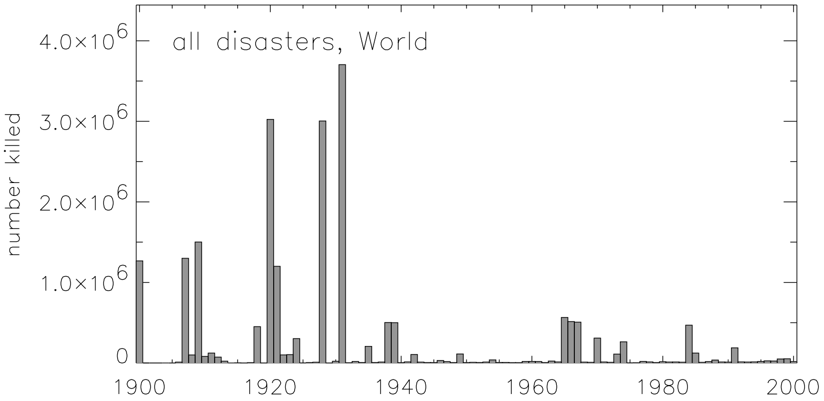


**Figure 4. Annual worldwide totals of people killed by climate-related disasters.**

Individual events stand out in the data. For example, a notable peak in the global and African drought series occurs in the early 1980s (Figure 5), when the dry episode in the Sahel was at its most severe and drought affected a large number of countries in sub-Saharan Africa. Droughts are also prominent in series for West Africa for the early 1970s, 1910s and 1940s (Figure 5), reflecting episodes recorded in rainfall timeseries and other records (e.g. Hulme, 1996). Such results demonstrate that the EM-DAT data do capture at least some of the major climate-related disasters of the twentieth century, even prior to the era of more reliable recording spanning the last two to three decades of the twentieth century. Interest in African drought has a long history, and the African drought frequency timeseries suggests that these particular data may be fairly reliable from the mid-1960s. However, in other cases data are sparse or absent until near the end of the century. For example, reporting of heat waves and cold waves increases notably in the 1980s. This may be a result of increased interest in temperature extremes resulting from a focus on anthropogenic greenhouse warming, or a result of changing temperature patterns

– most of the observed global warming to date has occurred since 1970 (IPCC, 2001a). Similarly, while almost no floods are recorded for South America prior to the late 1950s, after 1960 there is a large increase in recorded flood frequency, with consistently high frequencies from the late 1970s onwards. No South American wildfires are recorded before the mid-1980s, and recorded drought frequency for the continent increases after 1980.

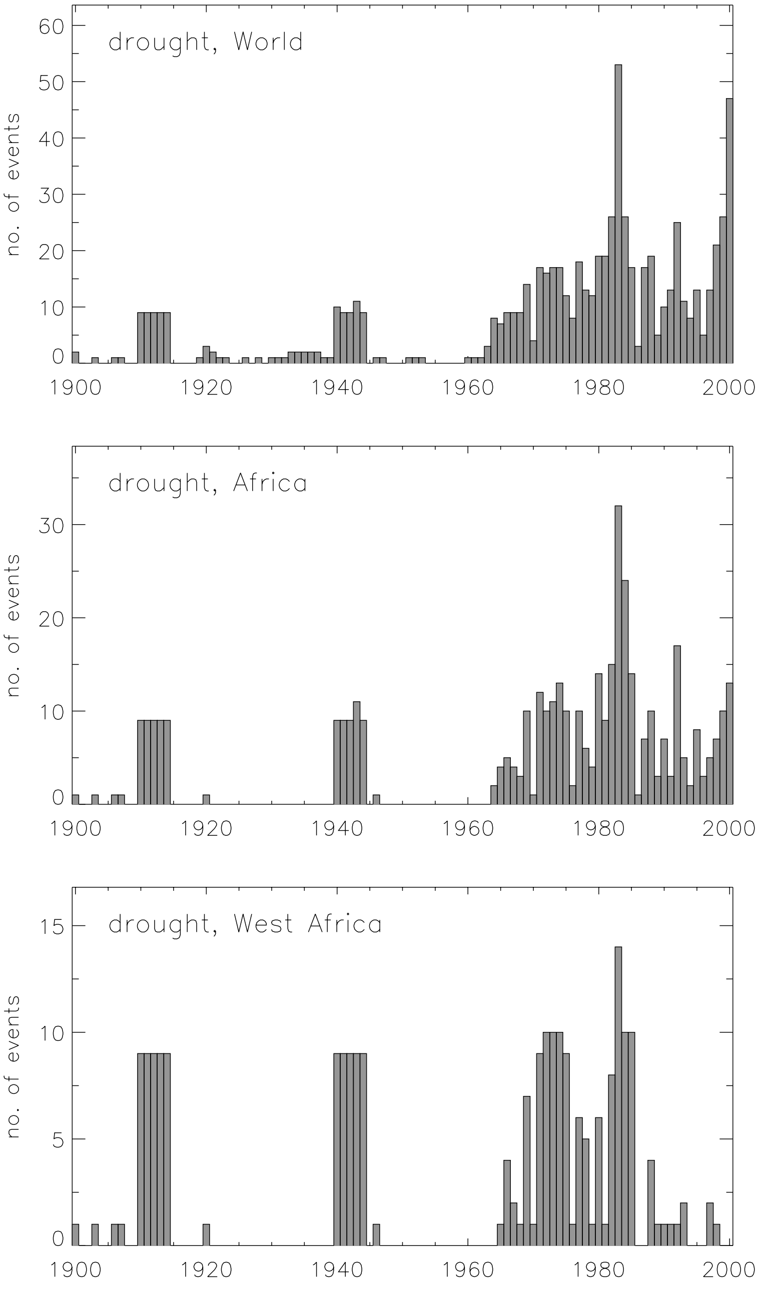


**Figure 5. Drought frequency time series for the world, Africa and West Africa, demonstrating the significance of the Sahelian drought of the early 1980s, and earlier droughts in the 1910s and 1940s.**

Despite these discontinuities in the records of individual disaster types for certain regions, the global number of disasters per annum remains relatively constant between the mid-1960s and the late 1970s. Between the late 1970s and the early 1980s the number of disasters rises quite sharply. Between the mid 1980s and the late 1990s the numbers remain fairly constant. The number of disasters rises sharply from 1998, with the largest increase being observed in 2000. The year 2000 is associated with the highest disaster frequency for all event types except insect infestations, droughts and windstorms; 2000 exhibits the second highest global recorded drought frequency after 1983, and the third highest windstorm frequency after 1990 and 1993. This pattern is not reflected in the aggregate killed-plus-affected series.

A plausible interpretation of these results is that the stabilisation in the recorded global frequency of climate-related disasters after about 1980 is the result of relatively consistent recording practices in the last two decades of the twentieth century. However, this does not explain the sudden rise in these types of event from 1998. The creation of new states in the 1990s may offer a partial explanation, as cross-border events were recorded in more than one country. However, the number of events increases from around 240 in 1997 to over 300 in 1999, and to almost 500 in 2000, increases that are much greater than the number of new states. The increase in climate related disasters at the end of the twentieth century may well represent a real increase in global climate hazards arising from changes in the climate system. While increases in vulnerability are likely to have contributed to the increase in the number of events, it is difficult to explain the dramatic and rapid upturn right at the end of the century simply in terms of changes in vulnerability.

As far as the validity of the data are concerned, data relating to events occurring in the 1980s and 1990s are likely to be most representative of reality. Risk assessments based on EM-DAT therefore are likely to be most reliable for the final two decades of the twentieth century, although assessments of vulnerability to particular disaster types during the 1970s, and possibly the 1960s, may be realistic for some regions. Variations in data coverage between countries will be considerable, some having long records stretching back to the first half of the twentieth century, and others having records covering only a few years (particularly new states created since the end of the Cold War). In most cases data coverage is likely to have improved as a result of improved communications, an increase in disaster awareness and the presence of international bodies undertaking disaster relief, although in some cases coverage will have deteriorated in recent years, particularly if a country has suffered from conflict or other widespread societal disruption. For most countries, data for periods prior to the 1970s or 1960s are unlikely to be particularly reliable.

### 4.4. Construction of risk proxies from EM-DAT

The EM-DAT data tell us about the (recorded) outcomes of disasters; we can therefore use them to construct indicators of outcome risk as defined by Sareiwitz et al (2003), discussed in section 3.3. above. As risk is a product of hazard and vulnerability, indicators that seek to represent the risk to a country associated with climate hazards must capture a representative sample of hazard events of the type that routinely affect that country. Representative here means representative in terms of frequency, severity and human exposure to the impacts of these events. As a corollary of this requirement, we must explicitly consider timescale: over what period are we measuring risk, and what sort of events might we expect to occur over this period? For example, it makes little sense to attempt to assess outcome risk associated with a hazard that typically occurs every few years by comparing the numbers of people affected by that hazard in different countries for a single year. Such a comparison would yield very different results if carried out for different years. As climate hazards do not generally occur every year (at least in their more severe incarnations), we must examine outcome risk over longer periods for any such assessment to be meaningful.

On the other hand, we must ask ourselves whether we should be concerned with events that recur on very long timescales. While severe long return period events have the potential for severe adverse impacts, the way in which these impacts are mediated by human vulnerability will vary over time. If two such events are separated by a number of decades, or even centuries, the social, economic and political processes that to a large extent determine their outcomes are likely to be very different. In other words, historical analogy is of limited use over long periods, and outcome-based measures of risk incorporating data from decades or centuries in the past will be of little use in predicting outcomes from hazards occurring in the near future. Understanding the likely impacts of such events in the near future, and identifying countries, regions and populations at high risk with a view to intervention to reduce this risk is the ultimate aim of risk assessment.

Further, societies are more likely to be concerned with the kind of hazard events that they are likely to face in the near future, rather than in the longer term. These near term hazards have the potential to undermine development and exacerbate vulnerability, and governments are more likely to be concerned with threats on timescales within the policy horizon, which is usually a few years. While climate change may bring new hazards in the future, high levels of risk associated with recent climate variability are likely to be associated with high risk arising from climate change, as climate change is most likely to be manifest in terms of changes in the frequency and severity of existing hazards. Societies that cope poorly with existing hazards need to reduce their vulnerability in order to cope with both existing climate variability and changes in variability arising from climate change in the near future. As argued previously, adaptation to current climate is a prerequisite for adaptation to climate change.

Risk assessment should therefore be carried out using periods long enough to ensure that assessments are representative of the types of hazard likely to be faced in the near future, but short enough that historical analogy is useful.

Here we assess risk associated with interannual to decadal scale climate variability by examining aggregated outcomes for the periods 1971-1980, 1981-1990 and 1991-2000. From the point of view of current risk associated with this short to medium term climate variability, data relating to the period 1990-2000 are most appropriate. Nonetheless, data relating to the two decades prior to this period are useful, as they yield information about the evolution of vulnerability for a particular country, provided changes in, and the reliability of, the data coverage for that country are taken into account. Consistency in the risk ranking of a country over these three periods also indicates that the results of any risk assessment are likely to be relatively robust, while dramatically different results in the three different sets of results may indicate that a particular result should be examined in more detail. Very different outcomes in different decades for the same country may be the result of large changes in reporting practices or in socio-economic and political conditions, or of the occurrence of a very few hazard events with multi-decadal return periods.

Data coverage is poor for many data categories in EM-DAT. The numerical data categories (e.g. numbers killed, total affected) are often poorly represented prior to 1970, and even after this date data are scarce for certain countries and event types. In many cases a figure for numbers killed is not associated with a figure for numbers affected. While under-reporting of mortality is likely to be common, assessment of numbers affected is even more problematic. These caveats must be borne in mind when interpreting the results of studies carried out using EM-DAT. Incomplete data coverage meant that it was necessary to adopt strategies to deal with missing data.

Where a country is associated with a non-zero number of events over a given period, but no data are recorded for these events, the sums for the killed and affected categories were set to zero. As far as the potential for misleading values due to under-reporting is concerned, the complete absence of killed and/or affected data for the recorded events is qualitatively no different from a partial absence of data. In both cases the numbers killed or affected could be vastly underestimated if missing data are treated as zero-values. However, if the analysis were to be performed only for countries that had no missing data, the number of countries included would be so small that the results would be of little value, particularly for decades prior to the 1990s. Furthermore, events associated with high mortality and severe impacts are the most likely to be associated with estimates of numbers killed and affected. The treatment of missing entries as zero values is therefore unlikely to misrepresent major events, as long as the countries in question are reasonably integrated into the global community of nations and are not experiencing complete social breakdown or widespread conflict, which may make data collection impossible.

A number of alternative national-level risk indices were constructed using data representing the 'killed' and 'total affected' categories. On a per country basis, the total number of events was calculated for a given time period over which risk was to be assessed. The entries for numbers killed and total affected were summed separately for the same period, and the number of events for which data were present in each of these categories was also recorded. The risk proxy is therefore $RISK^{j}_{i,t}$ where j refers to five alternative specifications outlined in Table 4, i = country, and t = time period (1971-80, 1981-90, 1991-2000). Where the risk indicator is scaled by national population, the population data represent the middle year of the decade in question (1975, 1985 and 1995).

**Table 4. Five proxy indicators of climatic risk. Subscripts i and t indicate that each value represents a particular country (i) over a particular period (t).**

| **Index** | **Description** |
|---|---|
| $RISK^1_{i,t}$ | sum of killed and affected as per cent of national population |
| $RISK^2_{i,t}$ | numbers killed as per cent of national population |
| $RISK^3_{i,t}$ | absolute numbers killed |
| $RISK^4_{i,t}$ | ratio of killed to affected, calculated from the sums for these categories |
| $RISK^5_{i,t}$ | ratio of killed to affected, calculated as the mean of the same ratio for the individual events in which both categories are present |

The different proxies measure different types of outcome, for example $RISK^2_{i,t}$ and $RISK^3_{i,t}$ measure mortality risk, whereas $RISK^1_{i,t}$ is a combined measure of the risk of mortality, morbidity and displacement. $RISK^1_{i,t}$ is represented by the greatest data coverage, but the reliability of the "affected" data is poor. Comparisons across datasets[1] indicate large variations in the numbers of people in the "affected" category, suggesting that these data should be treated with a good deal of caution. However, mortality reporting is relatively robust across datasets (although there are still significant variations), suggesting that the most "reliable" indicators listed in Table 4 are those relating to mortality risk. The consequences of using different indicators of risk are explored by comparing the different indices in Table 4; in this respect this is as much an exercise in assessing the usefulness of the EM-DAT data for studies of risk as in assessing risk itself.

### 4.5. Results

*Percentage of population killed and affected as a proxy for risk*

Numbers of people killed or otherwise affected, expressed as a percentage of national population ($RISK^1_{i,t}$), are listed for the twenty highest scoring countries for the period 1990-2000 in Table 5. Ranks and percentages killed and affected are also given for these countries for the two previous decades.

The most at-risk countries according the results presented in Table 5 are nearly all developing countries. Approximately half of them show a high degree of consistency in their rankings over the three decades examined. Djibouti, Bangladesh and Fiji are in the

---

[1] Unpublished, presented at a meeting of Working Group III of the International Strategy on Disaster Reduction in Geneva in April 2003.

top twenty for all three periods. Antigua and Barbuda, Swaziland and Belize are in the top twenty for the two periods for which they are represented, while the Philippines and Laos are in the top twenty for two out of three periods, and relatively high in the rankings for the other period. Malawi and Zimbabwe are only represented by data for the two later periods; while they are only in the top twenty for 1991-2000, they have relatively high rankings for 1981-1990. China's ranking increases over time. The rankings of Kenya and Iran decrease from the 1970s to the 1980s, increasing again in the 1990s. The results suggest that $\mathrm{RISK}^1_{i,t}$ is a reasonable proxy for vulnerability, yielding results that are relatively robust over time, at least for those countries with higher scores.

**Table 5. Countries with highest percentages of their populations killed or otherwise affected by climate-related disasters for the decade 1991-2000, according to the EM-DAT data. Percentage values are listed, with ranks given in brackets for the earlier decades. Countries in the top twenty for more than one of the three periods shown are highlighted. The number of countries given at the base of each column is the number of countries listed in the database for which the calculated sum of killed and affected is greater than zero.**

| Country | 1971-1980 | 1981-1990 | 1991-2000 |
|---|---|---|---|
| Malawi | - | 42 (26) | 168 |
| **Antigua & Barbuda** | - | **134** (5) | **118** |
| Kiribati | 2 (52) | - | 105 |
| Guyana | - | - | 96 |
| Zimbabwe | - | 8 (48) | 95 |
| **Philippines** | **36** (17) | **48** (22) | **93** |
| China | 1 (63) | 27 (31) | 93 |
| Australia | < 1 (67) | < 1 (99) | 87 |
| **Swaziland** | - | **101** (8) | **85** |
| **Djibouti** | **167** (2) | **93** (11) | **83** |
| **Bangladesh** | **69** (12) | **234** (2) | **77** |
| **Laos** | **135** (3) | **20** (35) | **72** |
| Mongolia | - | < 1 (126) | 71 |
| Kenya | 2 (55) | 3 (60) | 65 |
| Iran | 3 (46) | < 1 (81) | 64 |
| Cambodia | - | - | 63 |
| Moldova | - | - | 61 |
| Tajikstan | - | - | 58 |
| **Belize** | **72** (9) | - | **58** |
| **Fiji** | **38** (15) | **86** (12) | **56** |
| *No. of countries in series* | *91* | *130* | *167* |

### *4.5.1. Relationships between risk rankings and data coverage*

It might be expected that those countries characterised by the best recording practices will have the highest scores simply as a result of high levels of data acquisition. To test this, national $\mathrm{RISK}^1_{i,t}$ scores over the ten-year periods under investigation were plotted against data coverage (Figure 6). In this case, data coverage was based on data from the 'total affected' category, as this generally makes by far the largest contribution to the 'killed plus affected' values and is therefore the most important determinant of the $\mathrm{RISK}^1_{i,t}$ scores. For each country, data coverage was measured as the percentage of recorded events associated with an entry in the 'total affected' category. The correlation between the coverage series and the proxy risk series was also calculated for each period. Correlations are relatively low (0.14, 0.25 and 0.20 for the 1970s, 1980s and 1990s respectively), although there is a slight tendency for higher coverage to be associated with higher values of total affected. Nonetheless, for coverage greater than about 40 percent (1970s and 1980s) and 60 percent (1990s), maximum $\mathrm{RISK}^1_{i,t}$ values are relatively constant. Also, the great majority of values is associated with coverage above these thresholds, and for all three periods full data coverage is associated with a very wide range of values, spanning most of the range of scores. An equivalent analysis based on $\mathrm{RISK}^3_{i,t}$ scores yields similar results. Correlations are lower and the minimum coverage values are 20 percent, 50 percent and 60 percent.

Figure 7 shows the distribution of recording frequencies in terms of the percentage of events associated with an entry for 'total affected', represented as the number of countries that have a recording frequency in a specified five per cent range. Coverage is significantly better for 1991-2000, with around sixty countries having full coverage. Notably, the number of countries with full data coverage decreases between the 1970s and the 1980s (from 44 to 30), and the number of countries with only around 50 percent coverage increases. Recording frequencies for numbers killed are much greater than those for total affected after 1980, with 100 percent coverage for over a hundred countries for 1981-1990 and 1991-2000, and 37 countries for 1971-1980 (not shown). Frequency distributions are similar to those for 'total affected' for the 1980s and 1990s when based on the percentage of recorded events associated with entries in *both* the 'killed' and 'total affected' categories; the numbers of countries for each five percent interval are generally only slightly lower than in the 'total affected' cases. There are 17, 21 and 53 countries with full coverage in both data categories for the 1970s, 1980s and 1990s respectively.

These results strongly suggest that factors other than data density are responsible for the differentiation in $\mathrm{RISK}^1_{i,t}$ rankings between countries. Furthermore, in none of the periods examined are the twenty countries with the highest $\mathrm{RISK}^1_{i,t}$ scores consistently represented by the best data coverage (Table 6). Despite the fact that 43, 30 and 59 countries have full data coverage in the 'total affected' category for the 1970s, 1980s and 1990s respectively, no more than 5 of the countries with the twenty highest $\mathrm{RISK}^1_{i,t}$ scores have full coverage in this category for any of these periods. A number of high-scoring nations are characterised by relatively low data densities. While it is often the case that a country will have a high $\mathrm{RISK}^1_{i,t}$ score for a single decade with good data coverage, and low scores for the remaining poor-coverage decades, the converse is also true in some cases.

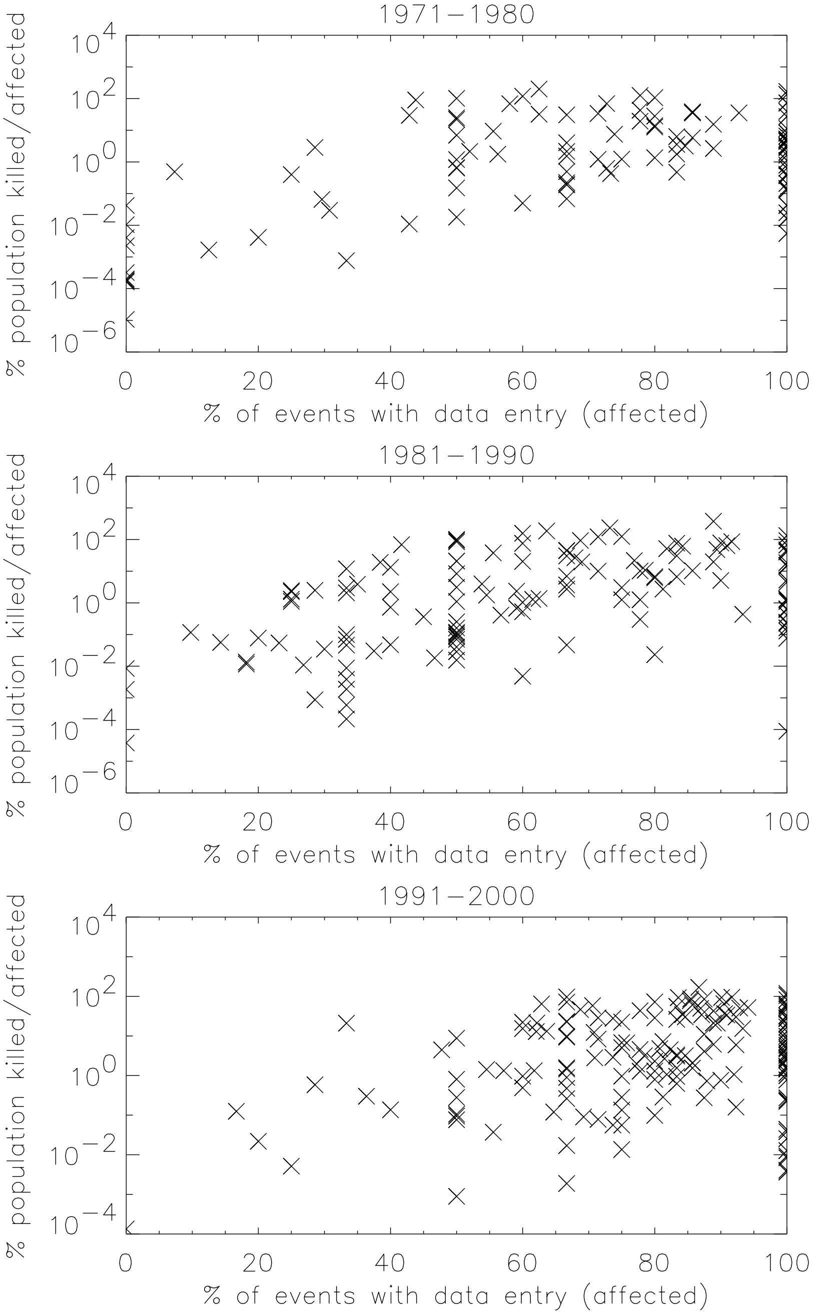


**Figure 6. Scatterplots of $RISK^1_{i,t}$ scores versus percentage of recorded events with an entry in the 'total affected' category for the period in question. Each cross represents a single country. Non-zero values occurring at zero coverage are the result of data being present in the 'killed' category only.**

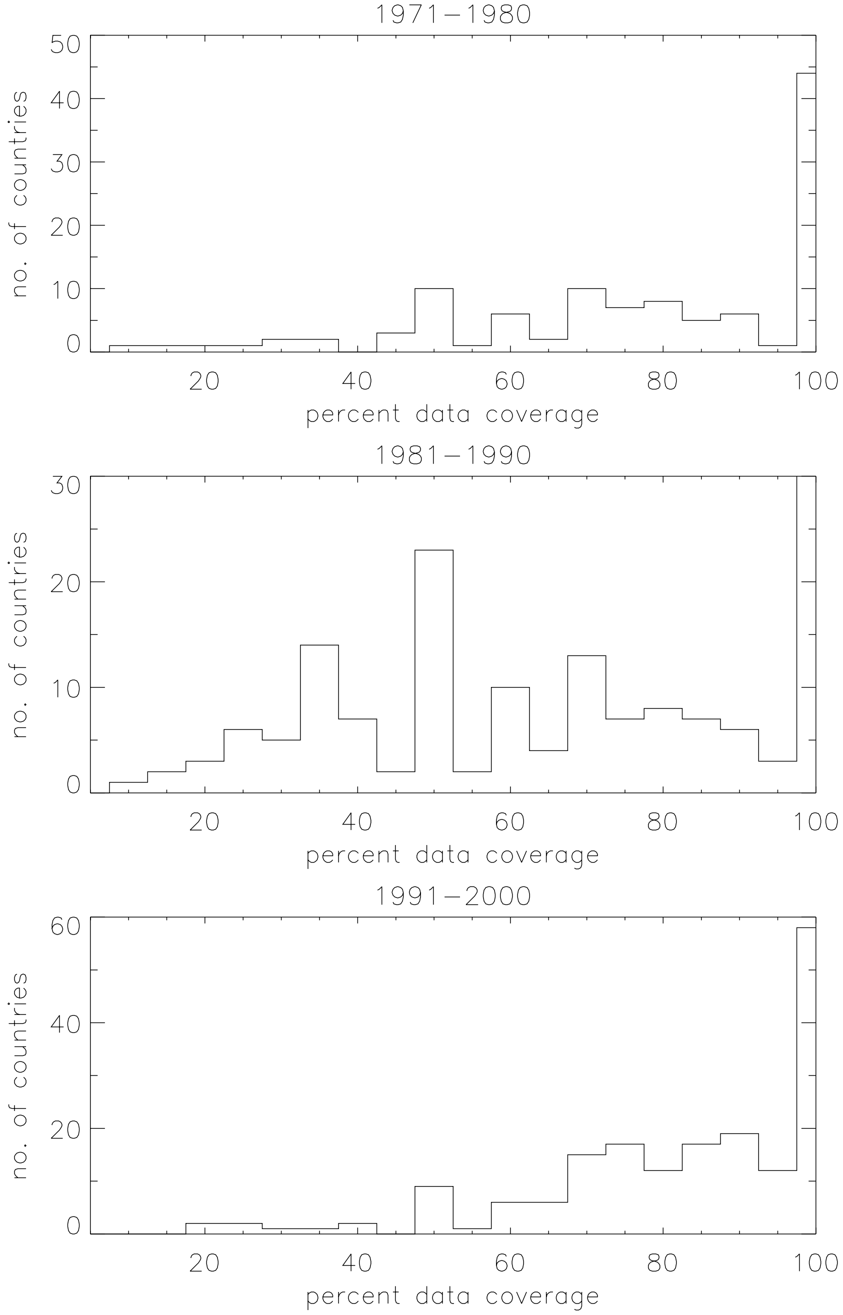


**Figure 7. Distributions of data coverage for entries in the 'total affected' category. 100 percent coverage corresponds to all events having an associated entry in this category.**

**Table 6: Percentage of events with an entry in the 'total affected' category (first column) and percentage of population killed or affected (second column) for the twenty countries with the highest $\mathrm{RISK}^1_{i,t}$ scores for the three decades examined.**

| **1971-1980** | | | **1981-1990** | | | **1991-2000** | | |
|---|---|---|---|---|---|---|---|---|
| Mauritania | 63 | 200 | Botswana | 89 | 378 | Malawi | 87 | 168 |
| Djibouti | 100 | 167 | Bangladesh | 73 | 234 | Antigua/Barbuda | 100 | **118** |
| Laos | 100 | 135 | Mauritania | 64 | 187 | Kiribati | 100 | 105 |
| Senegal | 78 | 126 | Tonga | 60 | 158 | Guyana | 67 | 96 |
| Gambia | 60 | 120 | Antigua/Barbuda | 100 | 134 | Zimbabwe | 92 | 95 |
| Mauritius | 80 | 107 | Samoa | 75 | 125 | Philippines | 90 | **93** |
| Dominica | 50 | 102 | Vanuatu | 72 | 122 | China | 84 | 93 |
| India | 44 | 91 | Swaziland | 50 | 101 | Australia | 86 | 87 |
| St Lucia | 100 | 74 | ST Principé | 50 | 94 | Swaziland | 83 | **85** |
| Belize | 100 | 72 | Mozambique | 69 | 94 | Djibouti | 100 | **83** |
| Mozambique | 73 | 70 | Djibouti | 100 | 93 | Bangladesh | 86 | **77** |
| Bangladesh | 58 | 69 | Fiji | 69 | 86 | Laos | 80 | **72** |
| Vietnam | 78 | 43 | India | 100 | 85 | Mongolia | 67 | 71 |
| Madagascar | 100 | 39 | Benin | 92 | 78 | Kenya | 91 | 65 |
| Fiji | 86 | 38 | Ethiopia | 50 | 77 | Iran | 63 | 64 |
| Honduras | 86 | 37 | Sudan | 67 | 76 | Cambodia | 100 | 63 |
| Philippines | 93 | 36 | Niger | 42 | 69 | Moldova | 86 | 61 |
| Nepal | 86 | 35 | Solomon Is. | 100 | 67 | Tajikstan | 71 | 58 |
| Niger | 71 | 34 | Bolivia | 91 | 64 | Belize | 100 | **58** |
| Mali | 63 | 32 | Sri Lanka | 85 | 62 | Fiji | 84 | **56** |

*4.5.2. Ratio of numbers killed to total affected as an indicators of risk*

The other measures of risk listed in Table 4 yield additional information, complementing the $\mathrm{RISK}^1_{i,t}$ results. For example, the latter yield a high score for Australia for 1991-2000, which is at number 8 in the $\mathrm{RISK}^1_{i,t}$ ranking. However, Australia is 88th in the ranking based on absolute numbers killed for the same period ($\mathrm{RISK}^3_{i,t}$). Its positions in the rankings based on the two different ratios of killed to affected are 157 ($\mathrm{RISK}^4_{i,t}$) (the second lowest non-zero score) and 124 ($\mathrm{RISK}^5_{i,t}$) (again one of the lowest scores). We may interpret these results as indicating that Australia is characterised by efficient reporting of events that may affect large numbers of people, but which do not cause high mortality. This is probably a function of the country's ability to undertake evacuation and provide effective emergency assistance in the event of climate-related disasters, the most important of which are probably forest fires in terms of the data under analysis here.

Poor reporting practices, focusing on high-mortality events and the numbers killed by them, will result in a country having a high score in the assessments based on the ratio of killed to affected. Examples are Spain and Greece, which record ratios of killed to affected of 11 and 6 for 1971-1980 and 1981-1990 respectively for $\mathrm{RISK}^4_{i,t}$ (calculated from killed and affected sums for the decade in question). Wealthy developed nations may score highly in the $\mathrm{RISK}^4_{i,t}$ and $\mathrm{RISK}^5_{i,t}$ categories if their infrastructure is such that most people remain relatively unaffected by climatic extremes. The events that are recorded in such cases are likely to be local events occurring in rural or inaccessible areas that kill small numbers of people. For example, Sweden, The United States, the United Kingdom, Switzerland, France, Iceland and Canada all appear in the top twenty for at least one decade in the $RISK^4_{i,t}$ and/or $RISK^5_{i,t}$ results. Such measures are more likely to give a distorted view of risk than $RISK^1_{i,t}$. However, a high score in both the $RISK^1_{i,t}$ and the $RISK^{4/5}_{i,t}$ rankings reinforces the interpretation that a country is particularly at risk, as such a result indicates that a climatic extreme is likely to affect large numbers and result in high mortality, and that for those affected by such events, the risk of death is relatively high when compared with other countries. Countries that score relatively highly in both types of assessment are Kiribati, the Philippines, China, Bangladesh and Iran.

Scores based on the ratio of numbers killed to affected are more consistent with the $RISK^1_{i,t}$ scores when this ratio is calculated as an average of the killed-to-affected ratio for each individual event ($RISK^5_{i,t}$). The top-scoring countries in the $RISK^5_{i,t}$ rank are Ecuador, Egypt and Democratic Republic of Congo, which score 3.3, 2.7 and 2.3 for the 1970s, 1980s and 1990s respectively. While these results may be inflated due to low estimates of numbers affected, they may not be as distorted as the high values for Spain and Greece given above for $RISK^4_{i,t}$. Other $RISK^5_{i,t}$ values are significantly lower and appear to be more 'realistic', and the majority of high-scoring countries are developing nations whose relative poverty, high population densities in vulnerable areas, and under-developed infrastructure might be expected to lead to high mortality from climate-related disasters.

### *4.5.3. Mortality as an indicator of risk*

In terms of numbers killed, the results also broadly reinforce the conclusions drawn from the $RISK^1_{i,t}$ analysis, but nonetheless refine our understanding of risk somewhat. Many of the countries with the highest $RISK^1_{i,t}$ values also score highly in terms of numbers killed expressed both as a percentage of population ($RISK^2_{i,t}$), and in absolute terms ($RISK^3_{i,t}$). Table 7 shows the thirty top scoring countries for both categories. Bangladesh, China and the Philippines have consistently high $RISK^3_{i,t}$ scores, remaining in the top ten (Bangladesh is ranked at 3, 5 and 1 for successive decades). Iran is in the top ten for the 1970s, but its score decreases over time, and Kenya scores relatively highly for the 1990s. Ethiopia, India, Honduras and Vietnam score consistently highly; so do the United States, Indonesia, Peru and Mexico. These results are somewhat different when numbers killed are expressed not in absolute terms, but as a percentage of population. For example, the United states disappears from the top thirty; although it may experience relatively high mortality rates, the numbers of people killed are small compared with its population. Good recording practices may also increase the rank of the United States in the $RISK^3_{i,t}$ category.

A notable feature of the $RISK^3_{i,t}$ results is that many small island states score relatively highly. The following small island developing states all appear in the top thirty most risky countries using this measure: the Maldives, Domincan Republic, Fiji, Guam, St Lucia, Haiti, Vanuatu, Sao Tome Principe, Solomon Islands, Cape Verde, French

Polynesia. A number of factors make small island states particularly vulnerable to natural disasters (Pelling and Uitto, 2002). The results of this study further demonstrate that many small islands are especially at risk from climatic events, even if the potential impacts of future sea-level rise are ignored.

**Table 7. Countries with highest numbers of people killed, expressed in absolute terms ($RISK^3_{i,t}$) and as a percentage of population ($RISK^2_{i,t}$). Countries which are also in the top twenty in terms of percent of population killed and affected ($RISK^1_{i,t}$, see Table 4) are highlighted in bold.**

| | **1971-1980** | | **1981-1990** | | **1991-2000** | |
|---|---|---|---|---|---|---|
| **Rank** | $RISK^3_{i,t}$ | $RISK^2_{i,t}$ | $RISK^3_{i,t}$ | $RISK^2_{i,t}$ | $RISK^3_{i,t}$ | $RISK^2_{i,t}$ |
| 1 | Ethiopia | Ethiopia | Ethiopia | Mozambique | **Bangladesh** | Honduras |
| 2 | India | Somalia | Sudan | Ethiopia | India | Venezuela |
| 3 | **Bangladesh** | Honduras | Mozambique | Sudan | Venezuela | **Bangladesh** |
| 4 | Somalia | Maldives | India | S T Principe | **China** | Guinea Bissau |
| 5 | Honduras | Dominica | **Bangladesh** | **Swaziland** | Honduras | Niger |
| 6 | **China** | **Bangladesh** | **China** | Somalia | Nigeria | Nicaragua |
| 7 | **Iran** | Bahrain | **Philippines** | Vanuatu | **Philippines** | Burkina Faso |
| 8 | USA | **Kiribati** | Afghanistan | Afghanistan | Peru | Somalia |
| 9 | **Philippines** | Gambia | Vietnam | Solomon Is | Vietnam | Peru |
| 10 | Brazil | Liberia | USA | St Lucia | Niger | **Djibouti** |
| 11 | Indonesia | Dom. Rep. | Somalia | **Bangladesh** | Burkina Faso | Tajikistan |
| 12 | Pakistan | **Fiji** | Indonesia | Mali | Nepal | Bhutan |
| 13 | Peru | **Iran** | Peru | Puerto Rico | Pakistan | Nepal |
| 14 | Japan | Oman | Brazil | Botswana | Somalia | Vanuatu |
| 15 | Korea (S) | Peru | Nepal | **Philippines** | Mexico | Zambia |
| 16 | Dom. Rep. | Guam | **Iran** | Comoros | Afghanistan | Cape Verde |
| 17 | Colombia | Hong Kong | Colombia | Burkina Faso | Tanzania | Haiti |
| 18 | Mexico | St Lucia | Nigeria | Peru | Indonesia | Togo |
| 19 | Mozambique | Mozambique | Mali | El Salvador | USA | **Laos** |
| 20 | Sri Lanka | **Philippines** | Mexico | Guatemala | **Kenya** | Gambia |
| 21 | Vietnam | Haiti | Korea (S) | Nepal | Sudan | Cameroon |
| 22 | Spain | India | Thailand | Sierra Leone | Nicaragua | Mozambique |
| 23 | Tanzania | Sri Lanka | Japan | Greece | Mozambique | Afghanistan |
| 24 | Thailand | Iceland | Greece | **Fiji** | Cameroon | **Philippines** |
| 25 | Nepal | Colombia | Burkina Faso | Cape Verde | Zambia | **Zimbabwe** |
| 26 | Liberia | Korea (S) | Guatemala | Angola | Tajikistan | C. Africa Rep. |
| 27 | Hong Kong | PNG | Angola | Fr Polynesia | **Zimbabwe** | **Swaziland** |
| 28 | Afghanistan | Vanuatu | South Africa | **Djibouti** | DR Congo | Iceland |
| 29 | Haiti | Nepal | Pakistan | Benin | Ghana | El Salvador |
| 30 | Argentina | Belize | Puerto Rico | Namibia | Russia | Nigeria |

## 4.6. Summary of EM-DAT based risk indicators

The results presented here suggest that consideration of a number of related proxies for risk associated with climate variability and change, based on numbers killed and affected by climate-related disasters, and constructed from datasets such as EM-DAT, enables us to make a relatively robust assessment of climate risk at the national level, while gaining some insight into the likely mechanisms that determine risk for different countries. The most appropriate proxy for risk based on the available national-level data data is the percentage of the national population killed or otherwise affected (i.e. requiring immediate assistance, including those injured or made homeless) due to a climate-related disaster, the $RISK^1_{i,t}$ proxy described in this study. The $RISK^1_{i,t}$ results are complemented by other, related proxies, particularly the percentage of the population killed by a disaster ($RISK^2_{i,t}$), and the ratio of numbers killed to numbers otherwise affected calculated as the mean of the ratios of killed to affected for individual disasters ($RISK^5_{i,t}$). We conclude that risk assessments benefit from the consideration of a number of indicators.

Except in a small number of cases, data coverage does not appear to be a significant determinant of risk rankings based on the above proxies, particularly for the $RISK^1_{i,t}$ scores. Data coverage is much better for the period 1991-2000 than for earlier decades. Nonetheless, the results appear to be fairly robust across the decades since 1970.

It is notable that a number of small island developing states score highly in this analysis, particularly in terms of the $RISK^1_{i,t}$ and $RISK^2_{I,T}$ scores. Because of their small land areas and low populations, when a disaster strikes a small island state, it is likely to affect a large percentage of the population. There is strong argument for treating small island states as special cases due to this and a number of other factors, particularly their vulnerability to sea-level rise, but also their isolation from, and dependence on trade with, other nations. These results show that, even without explicitly accounting for these factors, small island developing nations are particularly at risk from climate variability and change, a result supported by a number of other studies (Pelling and Uitto, 2001).

These results and lessons are, we argue, illuminating also in the context of adaptation to future climate states and risks. The analysis highlights a number of dilemmas in addressing priorities for adaptation, particularly in determining efficient adaptation action between the most vulnerable and those most likely to enhance adaptive capacity. Countries with different characteristics and from a range of geographical settings are at particular risk from climate variability and change. We are exploring causal relationships in subsequent work (see also Yohe and Tol, 2002). In the short term these countries would benefit from purposeful planning and vulnerability reduction programmes. However, it is not enough simply to identify vulnerable countries in terms of exposure to climate-related disasters; adaptation efforts by governments and civil society must be targeted at specific groups within these countries, and further research into the underlying causes of vulnerability at the sub-national scale are necessary.

# 5. DEVELOPMENT OF PREDICTIVE INDICATORS OF VULNERABILITY

## 5.1. Review of previous work on predictive indicators

There are many examples of the use of indicators to assess human and environmental security and vulnerability to various hazards and threats. Many sets of indicators have been developed to examine highly context-specific processes, such as the impact of socio-economic conditions on the management of coastal zones (Bowen and Riley, 2003) or ecosystem distress and human impacts on ecosystems (Kabuta and Laane, 2003; Rice, 2003). Bowen and Riley (2003) describe indicators as being "part of a process to minimize the number of individual variables and data points while maintaining a sufficient level of critical understanding".

Perhaps the most established form of vulnerability assessment is the analysis of food security, developed from the practical perspective of famine mitigation. Food security is often assessed at the household level, as it can vary dramatically between households, making larger-scale analyses misleading. Within the context of the conceptual framework presented above, food security assessments incorporating information relating to rainfall and vegetation cover may be viewed as assessments of the *risk* of famine (an outcome) resulting from drought hazard, mediated by vulnerability resulting from factors such as wealth, social status, livelihood, geographical location and institutional environment. Of course famine may be precipitated by factors other than drought, and famine may be viewed as one extreme of a spectrum of food insecurity (Downing et al, 2001); poor nutrition and even starvation for some members of a population may be the norm - under such conditions famine represents a step increase in mortality or morbidity outcomes as the result of the imposition of an external stress on an already highly vulnerable society. As the complexity of famine has become more apparent, indicators of food security have developed from simple measures of food availability to measures of people's access or entitlements to food, resulting from a variety of socio-economic as well as environmental factors.

There are a number of examples of national level indicators or sets of indicators that are relevant to studies of vulnerability. Some of these have been developed as indicators of general human welfare, economic well being or development status, while others specifically address national-level vulnerability.

Probably the most well-known national-level aggregate index relating to human welfare is the **Human Development Index (HDI)** developed by UNDP. The HDI is based on the earlier Physical Quality of Life Index and related to the Human Poverty Index, and is an aggregate measure of well-being based on education and health status, as well as income and inequality (Morris, 1979; Downing et al, 2001). Downing et al (2001) propose the HDI as a reasonable measure of "present criticality", which is equivalent to current vulnerability as described in section 2.1 above. The **Index of Sustainable Economic Welfare (ISEW)**, also known as the **Genuine Progress Indicator (GPI)**, is similar in some respects to the HDI, but concentrates on economic well-being adjusted by considering the costs of processes that might be detrimental to overall national well-being, such as environmental degradation, pollution and crime (e.g. Hamilton, 1999).

Another index of human welfare is the **Index of Human Insecurity (IHI).** Building on earlier work on indicators of sustainable development and incorporating research into human well being and social indicators, the Global Environmental Change and Human Security (GECHS) project has constructed the IHI explicitly addressing the question of how environmental degradation is related to human security. In a briefing paper (GECHS, 2000), human security is described as being achieved

> "when and where individuals and communities:
>
> - have the options necessary to end, mitigate, or adapt to threats to their human, environmental, and social rights;
> - have the capacity and freedom to exercise these option; and
> - actively participate in attaining these options.
>
> Moreover, attaining human security implies challenging the structures and processes that contribute to insecurities."

The paper presents national IHI values plotted against HDI scores, demonstrating an inverse relationship as might be expected.

An example of a composite index of human and environmental vulnerability is the **Environmental Vulnerability Index (EVI).** Developed by the South Pacific Applied Geosciences Commission (SOPAC), the purpose of the EVI is to represent the vulnerability of small island developing states (SIDS) to a range of natural and anthropogenic hazards, based on 47 indicators of vulnerability. These indicators include 27 representing risk, 7 of "intrinsic resilience" and 13 of "environmental integrity or degradation". The indicators are divided into 5 sub-categories: meteorological events (6 indicators), geological events (3 indicators) country characteristics (7 indicators equivalent to intrinsic resilience), biological characteristics (8 indicators) and anthropogenic factors (23 indicators). The indicators are chosen based on expert judgement, and the resulting indices are rated on a scale of 1 to 7, with 7 representing high vulnerability. The EVI has to date been applied to only a limited number of SIDS.

A more comprehensive assessment of human and environmental vulnerability is the **Environmental Sustainability Index (ESI)**. Developed by the Global Leaders of Tomorrow Environment task Force and the universities of Yale and Columbia, the ESI "measures overall progress toward environmental sustainability for 142 countries" using 20 indicators each comprising 2 to 8 variables, representing a total of 68 data sets (World Economic Forum, 2002a). The ESI comprises measures relative success for each country for five components: environmental systems, reducing stresses, reducing human vulnerability, social and institutional capacity, and global stewardship. Again, the indicators were chosen based on literature review and expert judgement. We will return to these components below in a discussion of the components of vulnerability and adaptive capacity for which we must identify appropriate indicators. A complementary and index, the **Environmental Performance Index (EPI)** has been constructed to assess air and water quality, greenhouse gas emissions and land protection World Economic Forum, 2002b).

Another example of a specifically targeted environmentally based index is the **Water Poverty Index (WPI)** developed by the Centre for Ecology and Hydrology in Wallingford, UK (Sullivan, 2002). The WPI "links physical estimates of water availability with socioeconomic variables that reflect poverty" (Sullivan, 2002).

The above indices are all relevant to the study of vulnerability and adaptive capacity, but none of them explicitly address the issue of vulnerability and capacity to adapt to climate variability or change, although the human vulnerability component of the ESI "seeks to measure the interaction between humans and their environment, with a focus on how human livelihoods are affected by environmental change." However, some studies have addressed the problem of how to measure vulnerability to climate variability and change, the most notable example being the Battelle study described by Moss et al (1999). This combines socio-economic factors with environmental factors to produce a vulnerability index, based on a conceptual framework including components representing food, water, settlements, health and ecosystems vulnerability. Each of these components is constructed from indicators of "coping capacity" and either "sensitivity" or "hazard exposure". This translates into a number of sectors, each represented by a variety of indicators, discussed in more detail in section 2.4.2. below. A summary of the structure of the conceptual framework is given in Downing et al (2001, pp 46-47).

The United Nations Environment Programme (UNEP) Division of Early Warning and Assessment (DEWA) and GRID-Geneva are developing a Disasters Risk Index under their **Global Risk and Vulnerability Trends per Year (GRAVITY)** project. This index will be used for systematic inter-country comparisons, and builds on GRID-Geneva's Project for Risk Evaluation, Vulnerability, Information and Early Warning (PREVIEW). Further information is available at http://www.grid.unep.ch/news/natural_hazard.php. The GRAVITY project examines four major hazard types: cyclones, droughts, floods and earthquakes. A major element of the project is to develop indices of human exposure to these hazards, using gridded data. The conceptual framework used by UNEP is represented by the following formula:

$$\text{Risk} = \text{frequency} \times \text{population} \times \text{vulnerability}$$

Where:
Risk = number of expected human losses per exposed population per time period
Frequency = expected (or average) number of events per time period
Population = number of people exposed to hazard
Vulnerability = expected percentage of population loss due to socio-political-economic context

(Peduzzi, 2000). This framework is quantitative in nature, allowing predictive modelling of risk to be carried out. Vulnerability is examined in terms of economic development, education, environmental quality, population and health and sanitation, and proxy data representing these factors have been correlated with mortality outcome data from EM-DAT in order to examine the importance of these different elements of vulnerability (Pascal Peduzzi, personal communication). The results of the GRAVITY project studies have not been published at the time of writing, and are due for release in September 2003.

The approach of UNEP/GRID-Geneva allows the construction of national level indicators of risk (and in principle of vulnerability) and the validation of these indicators using quantitative outcome data. This approach reflects the outcome-based risk assessments outlined in Section 4. In the GRAVITY project, overall risk associated with different types of hazard is calculated as the sum of the risk associated with individual types of hazard, providing an aggregated measure of risk comparable across countries. However the purpose of GRAVITY is to provide an assessment of recent/current risk associated with existing or historically familiar hazards. Vulnerability to the hazards assessed probably represents a good approximation of vulnerability to climate change, although we cannot necessarily say the same for risk. GRAVITY recognises the importance of response capacity, but the capacity to adapt to change and to anticipate and plan for climate change is not explicitly addressed, the emphasis being on disaster management and short-lived transient hazards.

### 5.2. Components of vulnerability and adaptive capacity

An understanding of the factors that constitute vulnerability and adaptive capacity is necessary if indicators of these quantities are to be developed. For national-level analyses we may conceptualise vulnerability by grouping its determinants into broad categories or sectors representing different societal and environmental aspects of vulnerability. This is the approach taken by Moss et al (1999); the sectors and indicators used in their study are listed in Table 8.

The Batelle study does not separate vulnerability and adaptive capacity; indeed in most of the literature there is no distinction between adaptive capacity and coping capacity. As suggested in section 3.4, adaptive capacity and coping capacity are not necessarily equivalent, and the relationship between them will depend on the nature of the hazard in question. For example, a system may *cope* with short-lived transient recurrent hazards by deploying tried and tested temporary measures for the duration of the hazard. If it copes successfully, once the hazard has passed, the system may revert to its pre-hazard state. At the time of onset of a short-lived hazard event, the vulnerability of a human system (such as a country) will be related to its capacity to cope with that hazard. Successful coping does not necessarily equate to adaptation, although lessons learned from a hazard event may result in the implementation of adaptation measures designed to increases the coping capacity of the system to similar future hazards. These lessons might also result in populations reacting differently the next time they are faced with a hazard - i.e. adaptation may be autonomous and manifest itself through a modification of coping strategies. The extent to which such adaptations occur is likely to depend on how successful existing coping measures prove - if they are successful and no damage is incurred as a result of the hazard, adaptation is likely to be minimal. The vulnerability of a system to a single short-lived hazard event, at the time of onset of that hazard, is a product of existing conditions and existing coping capacity; the capacity to adapt over all but very short timescales (i.e. at or below the duration of the hazard) is irrelevant.

**Table 8. Sectors and indicators used in Batelle vulnerability assessment, reproduced from Downing et al (2001).**

| Sector | Indicator |
|---|---|
| Food sensitivity | Cereals production per capita<br>Animal protein consumption per capita |
| Ecosystems sensitivity | Land managed, %<br>Fertiliser consumption |
| Settlements sensitivity | Flood prone population<br>Population without access to clean water and sanitation |
| Economic coping capacity | GDP per capita<br>Gini index |
| Human resources coping capacity | Dependency ratio<br>Completed Fertility<br>Literacy<br>Life expectancy |
| Environmental coping capacity | Population density<br>$SO_2$ emissions per area<br>Land unmanaged, % |

If a system is regularly damaged by recurrent hazards, or if the severity and/or frequency of hazards is expected to increase, deliberate efforts may be made to make the system more resilient in anticipation of future events. Such a process would constitute anticipatory adaptation designed to increase the coping capacity of a system over time, and might be undertaken by individuals and groups at local and national scales. The most potentially damaging manifestations of climate change, at least in the short to medium term, are likely to be changes in the frequency and severity of discrete recurrent hazards such as droughts, floods and storms. The vulnerability of a country to *climate change* will therefore depend on its capacity to adapt over time so as to increase its ability to cope with such events; the nature of the relationship between vulnerability and adaptive capacity (and between adaptive capacity and coping capacity) is crucially dependent on timescale, and vulnerability to climate change as described above is essentially vulnerability to discrete recurrent climate hazards integrated over time. Similarly, the ability of a system or country to cope with gradual changes in mean conditions (which are likely to be associated with changes in extremes) will depend on its ability to undertake responsive or anticipatory adaptation.

While such arguments may at first sight seem rather semantic, they are important in the construction of indicators as they demonstrate the importance of relating indicators and their constituent proxies to particular types or categories of hazard. If we are assessing impacts of and responses to current climate variability in the form of discrete, recurrent, transient events, we should develop separate of indicators of current vulnerability (incorporating coping capacity), and adaptive capacity (representing the ability of a system to change so as to make itself less vulnerable to such events in the future). Conversely, vulnerability to a gradually changing climate (i.e. vulnerability integrated over time) will be inversely related to adaptive capacity, and separate indices will not be appropriate. Nonetheless, many of the factors that determine current vulnerability will also determine the capacity to adapt over time, even if the processes and mechanisms are not equivalent.

As well as failing to address the complex relationship between vulnerability and adaptive capacity as mediated by the nature of climate hazard, the Battelle study (Moss et al, 1999) does not capture the aspects of governance that determine the institutional and political environment which mediates vulnerability and within which adaptation must be carried out. The ESI does goes some way towards addressing governance, but is not constructed as a climate-specific index. Following the examples of Battelle, the ESI, and other studies, we may place indicators of vulnerability and adaptive capacity in a number of different categories, and extend these categories to include measures of governance and other factors that have been neglected in these studies. Table 9 lists a number of studies and the associated categories or sectors into which variables are placed, which may be used as a basis for choosing categories and assigning indicators to these categories for studies of vulnerability and capacity to adapt to climate variability and change.

Current vulnerability to a recurrent hazard will depend on the extent to which populations and systems are exposed to the direct physical impacts of that hazard, and the extent to which they can absorb and recover from those impacts. These direct impacts may affect individuals, communities, infrastructure, ecosystems and other aspects of the physical environment. Individual resilience to drought and subsequent food shortages, for example, will be compromised by poor health and nutrition, in turn associated with poverty and inequality. The resilience of agricultural systems to drought be determined by the extent to which existing coping measures such as irrigation and water saving measures are in place. The resilience of settlements will depend on their location and construction, while that of ecosystems will depend on the extent to which they experience multiple stresses such as fragmentation, pollution and unsustainable exploitation.

The principal determinant of a society's capacity to adapt to change is likely to be access to resources (Blaikie et al, 1994; Twigg, 2001; Adger et al., 2003). As such access is determined by entitlements which are often the product of external political factors, it makes sense to include in our construction of an index of adaptive capacity factors representing processes operating at the super-national scale but which have consequences at the sub-national level. International trade and multilateral agreements that influence national economic policies are good examples. Poverty, inequality, isolation and marginalisation can all undermine the entitlements of individuals and groups. Along with environmental degradation and conflict, these factors can also reduce a society's resource base. Within any given system, all of these processes are influenced to a greater or lesser extent by the actions of individuals and groups outside the system, as well as by "natural" processes – for example vulnerability to coastal flooding may be exacerbated by drought that leads to migration to from inland agricultural areas to high-risk but economically productive coastal areas.

**Table 9. Categories of analysis for studies relevant to vulnerability and adaptive capacity assessment.**

| Study | Categories/sectors | Purpose of study |
|---|---|---|
| Battelle | | Vulnerability to climate change index |
| ESI | Basic human sustenance<br>Environmental health<br><br>Science technology<br>Capacity for debate<br>Environmental governance<br>Private sector responsiveness<br>Eco-efficiency | Assessing vulnerability component of sustainability<br><br>Social and institutional capacity component of sustainability |
| CVA | Physical/material<br>Social/organisations<br>Motivational/attitudinal | Designing relief interventions, disaster preparedness and mitigation. |
| HSI (generic) (cited in Brecke 2002) | Economic insecurity<br>Food insecurity<br>Health insecurity<br>Personal insecurity<br>Environmental insecurity<br>Community/cultural insecurity<br>Political insecurity | Development of an index of human insecurity - suggested format for International Week 2000. |
| Yohe and Tol, 2002 | Technological options<br>Resources and their distribution<br>Institutions/decision making<br>Education & human insecurity<br>Social capital/property rights<br>Access to risk spreading<br>Information management<br>Attribution/significance | Determining components of, defining and operationalising adaptive capcity; based on criteria in IPCCTAR Ch.18 (IPCC, 2001). |
| UNEP/GRID-Geneva | Enhancing physical factors<br>Socio-economic factors<br>Response capacity | Development of disaster risk index |

If we include in our definition of adaptive capacity all the factors that facilitate and inhibit adaptation, adaptive capacity at any given point in time represents the degree to which a system will "automatically" adapt, and will be a function of the following:

i. Recognition of the need for adaptation
ii. Belief that adaptation is possible and desirable
iii. Willingness to undertake adaptation
iv. Availability of resources necessary for implementation of adaptation strategies
v. Ability to deploy resources in an appropriate manner
vi. External constraints on, or obstacles to, the implementation of adaptation strategies

In order to construct indicators of vulnerability to climate change, i.e. vulnerability integrated over time, we must consider vulnerability to discrete recurrent hazards in combination with the capacity to adapt so as to cope with increases in their frequency and severity, as well as with new hazards. The best guide to near-future vulnerability to discrete events is probably current vulnerability to such events; current vulnerability to recurrent climate hazards may therefore be viewed as a component of vulnerability to climate change assessed over an extended period.

### 5.3. Definition of indicators and choice of proxies

Following on from the above discussion and the material in Table 9, we can identify key groupings of factors representing vulnerability to climate change, analogous to the categories and sectors reviewed above. Groupings and appropriate proxies for vulnerability are discussed below; this discussion seeks to include previously neglected determinants of vulnerability and to expand on the studies reviewed above. Lists of suggested proxies for each grouping are given, based on a both the nature of the factors and processes to be represented and the availability of data. A complete list of the proxy data used, and alternative proxy variables, is given in Table 10. at the end of this section, along with details of the data sources. The combination or aggregation of different vulnerability proxies to construct vulnerability indicators is discussed in section 5.5. below.

*1. Economic well-being (EC)*

Although vulnerability does not simply map onto poverty, poor communities often face greater levels of risk than more affluent populations (United Nations, 2001; Wisner, 2000). Poor people are more likely to live in hazard-prone locations such as unstable hill slopes and flood plains. The poor, who in many cases may have migrated from rural areas to exploit perceived economic opportunities in cities, often live in slums with little or no sanitation or access to clean water. Poor sanitation, as well as overcrowding, will increase the risk to urban populations of the secondary health effects of flooding and other hazards by increasing the likelihood of water-borne disease. Hastily constructed settlements are more physically vulnerable to the immediate impacts of events such as extreme rainfall and wind storms, increasing the risk of physical injury for their inhabitants. While such settlements may be less expensive to reconstruct than more "permanent" residential areas, those who inhabit them will be less able to afford risk spreading measures such as insurance, and will be less able to engage in post-disaster reconstruction. The livelihoods of the poor are therefore more vulnerable to these hazards than those of the better off, and disasters associated with climate and other hazards can exacerbate poverty, increasing vulnerability.

At the national level, a lack of financial resources will adversely affect a country's ability to recover from the impacts of extreme events in terms of rebuilding infrastructure and reinvesting in damaged areas and sectors, and the exacerbation of poverty and vulnerability by disasters alluded to above also operates at the national level (Comfort et al., 1999). However, poverty-related vulnerability cannot be represented by a single variable such as GDP. If wealth is very unevenly distributed, a country with a relatively high GDP may still contain very poor population groups who are vulnerable to climate hazards for the reasons outline above. Furthermore, a country's ability to pay for emergency planning and disaster reconstruction will be affected by its indebtedness, i.e. the extent to which the national wealth is diverted into servicing loans. Economic policy in highly indebted countries is very often determined by the international financial institutions, which impose structural readjustment and trade liberalisation programmes that reduce the capacity of the state to pursue policies that reduce vulnerability associated with poverty (Comfort et al., 1999). Ndikumana and Boyce(2003) also find that debt can encourage capital flight, further exacerbating national economic well-being.

While adaptation need not necessarily be costly, research into adaptation to climate change requires funding and an active research community. Poor countries often have more immediate priorities than anticipating future climate change, for example responding to disasters resulting from current climate variability. While these activities can, and indeed should, be complementary, national level adaptation may be hindered by limited financial resources.

National-level indicators of economic well-being should therefore capture the total wealth of a country, its distribution, and the opportunity of a national government to formulate and implement economic policies that enhance the well-being of it's the population that it governs.

Economic well being (EC) may be represented by the following proxy variables:

- GDP per capita
- Gini Index
- Debt repayments as a percentage of GDP.

*2. Health and nutrition (HN)*

People in poor health, and those who are undernourished, will be more vulnerable to the immediate and secondary impacts of extreme events, whether this take the form of direct physical injury or a more complex impact such as food shortage or famine. A population in poor general health is less likely to be prepared for a disaster, and less likely to be able to cope with the impacts of a disaster in the short term. Ill health can remove individuals from the economically active population, and the sick must be cared for either by the state or society at large. The removal of the most economically active members of society as a result of the HIV/AIDS epidemic in Africa is a striking example. Families caring for sick relatives have less time, money and energy to invest in activities that might mitigate the impacts of external hazards, help them recover from hazard events and be better prepared for them in the future. Illness is intimately linked with poverty in terms of both cause and effect. Indicators of health therefore must capture the processes via which illness undermines the ability of individuals and the state to cope with hazards, and the burden placed by illness on the population at large, including those who are not sick. This burden will be greatest where it falls on immediate family members rather than being met by the state.

Health expenditure per capita is a reasonable proxy for the extent to which the burden of illness is borne by the state, while disability adjusted life expectancy (DALE) represents the overall general health of a population. DALE will capture the effects of diseases such as HIV/AIDS and malaria, another major health issue in the developing world. However, life expectancy and economically active life span may be severely reduced in the future by the impact of HIV/AIDS, particularly where large numbers of young people are currently infected. High infection rates will therefore reduce adaptive capacity by removing society those who would undertake most of the adaptation (the economically active).

Nutrition is also important. Poor nutrition is associated with poor general health and increases susceptibility to disease (for example epidemics following flooding) as a result of a weakened immune system. People who are already malnourished or who experience borderline malnourishment will be less likely to survive food shortages (for example associated with drought). Nutritional status is represented by calorific intake per person.

The health and nutrition (HN) category may be represented by the following variables:

- Health expenditure per capita (USD PPP or % of GDP)
- Disability adjusted life expectancy (DALE)
- Calorie intake per capita
- AIDS/HIV infection (% of adults)

Other proxies relating to agricultural production and food prices are available. However, production does not necessarily equate to availability. Agricultural production may be geared towards exports, and countries with small agricultural sectors may import food. Indeed, as agriculture is a climatically sensitive sector, low domestic production is likely to reduce vulnerability to climate change, provided a country can import sufficient food for its population. Food prices are a better indication of food security, but calorific intake is a more direct, and strongly related, measurement of nutritional status.

### *3. Education (EDU)*

Education is associated with poverty and marginalisation - the least educated and lower-skilled members of a society are likely to be the most vulnerable to climate hazards in terms of livelihoods and geographical location. They are also less likely to have a political voice and their welfare may therefore be a low priority as far as governments are concerned. Education provides the basis for a “scientific” understanding of the physical world, and thus forms the foundation for understanding the complex nature of hazards and appropriate responses to them, perhaps through the use of forecast data. Nonetheless, it must be recognised that indigenous knowledge and experience of the environment is in many cases at least as useful as a scientific understanding of climate hazards, and that forecasts and written information are generally unavailable to the most vulnerable members of the population. Again, education is strongly related to poverty and livelihoods; populations with overall low levels of education are more likely to depend on climate-sensitive economic activities such as agriculture.

The capacity to adapt to climate change in an anticipatory manner will depend strongly on the availability of information relating to climate change, and on the ability of those undertaking adaptation to interpret this information. Literacy will play an important role in determining access to information regarding the necessity for adaptation and the available of assistance from government to help people pursue adaptation strategies. Adaptation will inevitably be associated with conflicts of interest in some instances, and literate, educated populations will be in a better position to negotiate equitable solutions to potential conflicts.

The education category (EDU) may be represented by the following:

- education expenditure (% government expenditure or % of GNP)
- literacy rate (% of population over 15)

### *4. Physical infrastructure (INF)*

The quality and situation of settlements, commercial infrastructure and elements of transport systems will determine their physical vulnerability to the immediate impacts of events such as rainfall extremes, coastal inundation and wind storms. Quality and density of roads and other transport routes (e.g. rivers) will determine the ability of rural populations to access markets in order to sell livestock and other commodities in times of crisis, and will also influence the feasibility and efficacy of aid distribution programmes in response to disasters such as droughts, floods and famines. A tentative proxy for settlement quality might be rural-urban migration rates, given that migrants from rural areas are likely to be poor and live in hazard-prone areas in poor-quality housing. The isolation of rural communities will depend on the nature of transport networks, and may be captured by the density of the road network. The quality of sanitation infrastructure and the availability of clean water are also indicative of overall physical infrastructure (and are also strongly related to health status).

The physical infrastructure category (INF) may be represented by the following:

- roads, km, scaled by inhabited land area
- Population without access to sanitation (%)
- Rural population without access to safe water (%)

### *5. Institutions, governance, conflict and "social capital" (GOV)*

The way in which society at large acts collectively to confront hazards and reduce risk is a complex, yet extremely important, factor in determining vulnerability. The ability to act collectively is often described in terms of "social capital", a problematic term with many different definitions and interpretations. According to Lochner et al (1999), social capital "consists of those features of social organisation - such as networks of secondary associations, high levels of interpersonal trust and norms of mutual aid and reciprocity - which act as resources for individuals and facilitate collective action." Paldam and Svendsen (2000) define social capital more succinctly as "the density of trust" which "determines how easily people work together". For our purposes we are interested in how individuals, groups, organisations and institutions within a country interact and cooperate in order to address risk. In other words we are interested in governance: governance is not simply government, but also includes the complex interactions between and within government, business and "civil society" (Adger et al, 2003). The way in which individuals and groups within a society interact with each other will influence vulnerability through mechanisms such as risk sharing, mutual assistance and collective action (e.g. Adger, 1999).

State institutions play an important role in determining vulnerability. Inefficient or corrupt state institutions are associated with a lack of adequate healthcare, housing, and sanitation, and low levels of general development. A weak, inefficient or corrupt institutional infrastructure is likely to lead to a neglect of physical infrastructure and to increase inequality as certain groups are favoured through systems of patronage. In addition, weak and corrupt institutions will lead to inefficient and inadequate responses to disaster events, with calls for international assistance being delayed and aid not necessarily going to those whose need is greatest. Democracy and accountability are likely to be important in this respect, as governments that fail adequately to manage disasters and mitigate risk are less likely to be re-elected. Kosack (2003) finds that improvements in quality of life resulting from foreign aid are conditional on the presence of democracy. However, democratic societies will not automatically act to minimise vulnerability, especially where there is a high demand for settlement expansion and where the availability of insurance encourages people to settle in hazard-prone locations. The under-writing of risk by government can exacerbate vulnerability to natural hazards, and this process has a long history in industrialised capitalist democracies such as the United States (Steinberg, 2001).

Neumayer et al (2002) find that participation in a democratic system has a positive effect on environmental commitment at the international level (measured in terms of participation in multilateral environmental agreements), although the extent to which this translates into vulnerability reduction is debatable, particularly given the potential for conflict between efforts to conserve the physical environment and the promotion of human welfare (e.g. Adams and Infield, 2003; Fearnside, P. M., 2003). While we might expect democratic countries to make significant efforts to reduce the vulnerability of their populations to climate and other hazards, democracy may also serve as an obstacle to policy implementation, and encourage governments to pursue short-term populist policies that might exacerbate vulnerability. Governments in the United States and Britain have systematically diluted environmental commitments because of concerns that environmental legislation will alienate voters and business alike. Conversely, more autocratic regimes may have greater freedom to pursue policies designed to reduce vulnerability. Although it is unlikely to be sustainable in the long term, the Great Manmade River Project has increased the availability of fresh water for coastal populations in Libya, decreasing the risk from drought associated with low rainfall, high variability and an increasing population. One wonders whether such an expensive and controversial project would have been pursued in a more democratic society, where various interest groups and political opposition parties may have opposed the scheme on environmental and costing grounds. It might be argued that a more sustainable solution may have been found in a democratic society through greater consultation and exploration of alternative strategies to increase water availability, although such a contention would be probably be extremely difficult to support.

The application to vulnerability studies of data representing the degree of democratisation should therefore be treated with caution. Nonetheless, should we choose to use such proxies, several datasets are available. The most accessible is the Freedom House dataset of civil liberties and political rights, although Neumayer et al (2002) caution against using these data for comparisons across time because of the way the dataset is constructed.

Democracy in this context is not an end in itself. Other factors, while they may be associated with democracy, are likely to affect vulnerability in a more direct manner. The importance of corruption (or rather a lack of it), the effectiveness of state institutions, and political accountability has been mentioned above. Political stability will be necessary if there is to be continuity in policies intended to reduce vulnerability. Where there is little security, for example in terms of property rights, people will be reluctant to invest in adaptation as there will be no guarantee that they will benefit from place-based adaptive measures; the protection of property by law is therefore potentially important. The regulatory environment is another important factor, although the consequences of a strong regulatory environment may be positive or negative for vulnerability. Where policies are "adaptation friendly", strong regulation can ensure that adaptation is pursued and maladaptation avoided. However, where policies are "climate neutral" there is a risk that strong regulation will prevent people from pursuing autonomous adaptation. Many of these factors are represented by the dataset of Kaufmann, Kraay and Zoido-Lobaton (Kaufmann et al., 1999a and 1999b), referred to from here on as the KKZ dataset.

Internal conflict is another important factor. Countries experiencing civil conflict are unlikely to be in a position to address questions of vulnerability and adaptation, and the subsequent displacement of populations will increase vulnerability as livelihoods and traditional coping mechanisms are disrupted or destroyed. Conflict may be represented by the number of internally displaced persons.

Given the above considerations, we can represent governance-related factors (GOV) by the following proxies:

- Internal refugees (% of population)
- control of corruption (KKZ)
- government effectiveness (KKZ)
- political stability (KKZ)
- regulatory quality (KKZ)
- rule of law (KKZ)
- voice and accountability (KKZ)

It should be noted that there is a high degree of heterogeneity in the way the KKZ data have been collected, and that they are imperfect subjective measures of unobservable variables, based on a combination of surveys of business people and residents within the countries concerned and the expert judgement of individuals from outside these countries. The authors stress that the resulting errors in the data mean that these datasets can at best be used to place countries in groups, rather than compare governance between individual countries (Kaufmann et al., 1999b). They also caution against averaging across proxies for a particular country, or standardising proxies.

### *6. Geographical and demographic factors (GDEM)*

Geographical factors are extremely important in determining people's exposure to the physical impacts of climate hazards. For example low-lying areas will be more liable to flooding as a result of extreme rainfall events than higher elevation regions, and coastal areas will be subject to a range of hazards (from hurricanes to storm surges and wave erosion) that are absent from inland regions. Ideally we would gather data on the numbers of people living in different types of environment within a country, for example on flood plains and in low-lying coastal areas. However, such data are not universally available, and cruder proxies must be used. Nicholls and Small (2002) define the "near-coastal zone" as the area within 100 km of the coast and with an elevation of less than 100m above mean sea level. They argue that this zone represents the area in which populations are most likely to be exposed to the direct or indirect consequences of coastal hazards. Since coastal hazards are one of the major areas of concern with regard to climate change, it is appropriate to include measures related to exposure to coastal hazards in our list of geographic proxies. Coastal hazards are particularly important for small island states (SISs) for obvious reasons (Pelling and Uito, 2000), and failure to address them specifically will result in the indicators being biased such that the vulnerability of SISs is underestimated.

Population density will also influence vulnerability. Where it is high, vulnerability may be exacerbated by the locating of settlements in hazard-prone areas, and by stress on physical infrastructure such as sanitation systems. High population densities are associated with an increased risk of disease in the aftermath of certain natural disasters, resulting from a combination of pollution of water supplies with human waste and also from the close proximity of individuals to one another than facilitates the spread of disease. Densely populated countries are more likely to contain areas of very high population density where such problems can be acute. Population density should be calculated as the numbers of people per square km in the *inhabited* regions of the country. This may be illustrated by considering an extreme example such as Egypt, a country with a population similar to that of the UK and an area some four times the size of the UK, but in which most of the population live in the Nile Valley and a few scattered oases, representing only some 4% of the national land area.

The demographic and geographical (GDEM) factors described above may be represented by the following:

- km or coastline (scaled by land area)
- Population within 100 km of coastline (%)
- population density

### *7. Dependence on agriculture (AG)*

One of the principal hazards associated with climate variability and change is drought, and populations engaged in agriculture will be particularly at risk from drought. As agriculture is the major climate-sensitive economic activity throughout most of the world, it is appropriate to include a measure of a country's dependence on agriculture in the list of proxies. Dependence on agriculture may take the form of small-scale farming in which people depend directly on agriculture for their own nutrition, or agricultural exports that contribute significantly to GDP. The following proxies are useful in representing dependence on agriculture (AG):

- Agricultural employees (% of total population)
- rural population (% of total)
- Agricultural exports (% of GDP)

The agricultural employees proxy will underestimate the numbers of people directly dependent on agriculture as it is biased towards wage labour. The percentage of the total population living in rural areas is included to compensate for this, as rural populations are likely to be heavily dependent on agriculture.

### *8. Natural resources and ecosystems (ECO)*

The capacity to adapt to climate change will depend to a large extent on the availability of natural resources, particularly water resources. Increases in mean surface temperatures will lead to increased evapotranspiration and will increase the demand for irrigation in some parts of the world. While agricultural and irrigation systems may be adapted to reduce the demand for water (for example by shifting to crops that require less water or by increasing irrigation efficiency), some countries may find themselves increasingly drawing on non-renewable reserves from subterranean aquifers. Water availability will be determined by a combination of water from present-day precipitation or runoff and water from aquifers that have been recharged in past episodes of high rainfall. The latter is particularly important in arid and semi-arid regions.

Land is another important resource that enables people to move or expand settlements and agriculture, provided the necessary conditions are present. Even currently unproductive land may in principal be converted for agricultural use through the application of technology to problems such as soil infertility and water scarcity.

Land that is not currently used for agriculture also has significant utility value, through processes such as runoff reduction, water purification and other “ecosystem products and services”. It is therefore in the long-term interests of societies to preserve existing ecosystems and help them adapt to climate change. Ecosystem stress and destruction can increase the physical vulnerability of settlements (through processes such as flood exacerbation and increased erosion), as well as reducing the potential for people to exploit alternative food resources and livelihoods as part of the adaptation process. Deforestation, ecosystem fragmentation and pollution can all increase a country’s ecological vulnerability to climate change, as natural systems become stressed and are prevented from migrating in response to shifts in climatic zones.

Factors related to natural resources and ecosystems (ECO) may be represented by the following proxies:

- Protected land area
- Per cent forest cover
- Water resources per capita
- Groundwater recharge per capita
- Unpopulated land area (%)
- Forest change rate (% per year)

### *9. Technical capacity (TECH)*

The final category represents a country’s capacity to exploit science and technology in order to facilitate adaptation. Addressing climate change will involve assessments of vulnerability at the sub-national scale, and also of the hazards with which climate change risk is likely to be associated. Some of these assessments are likely to highly technical, particularly assessments of potential future hazards. The development of strategies to adapt to climate change will require expertise in a variety of fields including climatology, meteorology, geomorphology, hydrology, agricultural science, geotechnical engineering, and the social sciences. Adaptation will depend to a certain extent on the ability of a country to undertake quantitative and qualitative studies of the processes that determine vulnerability. Investment in tertiary education and research and development will represent a good basis for addressing the technical, scientific, social and policy aspects of adapting to climate change. Technical capacity (TECH) can be represented by the following proxies:

- R&D investment (% GNP)
- Scientists and engineers in R&D per million population
- tertiary enrolment

**Table 10. Potential proxies for national-level vulnerability to climate change. The data sources are: the World Bank (WB); Human Development Index (HDI); UNEP/GRID-Geneva (GRID); Kaufmann, Kray and Zoido-Lobaton governance dataset; Center for International Earth Sciences Information Network (CIESIN) at Columbia University; United Nations World Income Inequality Database (WIID).**

| Indicator | Variable | Proxy | Source |
|---|---|---|---|
| EC | national wealth | GDP per capita (US$ PPP) | WB |
| | inequality | GINI coefficient | WIID |
| | economic autonomy | Debt repayments (% GNI, averaged over decadal periods) | WB |
| | national wealth | GNI (total, PPP) | WB |
| HN | state support for health | Health expenditure per capita (US$ PPP) | HDI |
| | state support for health | Public health expenditure (% of GDP) | HDI |
| | burden of ill health | Disability adjusted life expectancy | WHO |
| | general health | Life expectancy at birth | HDI |
| | healthcare availability | Maternal mortality per 100 thousand | HDI |
| | removal of economically active population | AIDS/HIV infection (% of adults) | HDI |
| | nutritional status | Calorie intake per capita | GRID |
| | general food availability | Food production index (annual change averaged over 1981-90 and 1991-99) | WB |
| | access to nutrition | Food price index (annual change averaged over 1981-90 and 1991-99) | WB |
| EDU | educational commitment | Education expenditure as % of GNP | HDI |
| | educational commitment | Education expenditure as % of government expenditure | HDI |
| | entitlement to information | Literacy rate (% of population over 15) | HDI |
| | entitlement to information | Literacy rate (% of 15-24 year olds) | HDI |
| | entitlement to information | Literacy ratio (female to male) | HDI |
| INF | isolation of rural communities | Roads (km, scaled by land area with 99% of | WB |

| | | | |
|---|---|---|---|
| | | population) | CISEIN |
| | commitment to rural communities | Rural population without access to safe water (%) | HDI |
| | quality of basic infrastructure | Population with access to sanitation (%) | HDI |
| GOV | priorities other than adaptation | Internal refugees (1000s) scale by population | WB |
| | effectiveness of policies | control of corruption | KKZ |
| | ability to deliver services | government effectiveness | KKZ |
| | willingness to invest in adaptation | political stability | KKZ |
| | barriers to adaptation | regulatory quality | KKZ |
| | willingness to invest in adaptation | rule of law | KKZ |
| | participatory decision making | voice and accountability | KKZ |
| | influence on political process | civil liberties | FH |
| | influence on political process | political rights | FH |
| GDEM | coastal risk | km of coastline (scale by land area) | GRID |
| | coastal risk | Population within 100km of coastline (%) | GRID |
| | infrastructure/disease | population density | CIESIN |
| AG | dependence on agriculture | Agricultural employees (% of total population) | WB |
| | dependence on agriculture | Rural population (% of total) | WB |
| | dependence on agriculture | Agricultural employees (% of male population) | WB |
| | dependence on agriculture | Agricultural employees (% of female population) | WB |
| | agricultural self sufficiency | Agricultural production index (1985, 1995) | WB |
| ECO | environmental stress | Protected land area (%) | GRID |
| | environmental stress | Forest change rate (% per year) | GRID |
| | environmental stress | Percent forest cover | GRID |
| | environmental stress | Unpopulated land area | CIESIN |
| | sustainability of water resources | Groundwater recharge per capita | GRID |
| | sustainability of water resources | Water resources per capita | GRID |
| TECH | commitment to and resources for research | R&D investment (% GNP) | WB |
| | capacity to undertake research and understand issues | Scientists and engineers in R&D per million population | WB |

## 5.4. Validating the vulnerability proxy data

Once the proxies comprising each indicator have been chosen, the question remains as to how the indicators should be constructed/presented, and how to validate the proxies in terms of their utility and the extent to which they capture the elements of national-level vulnerability. These questions are related, particularly in terms of the appropriate weightings to apply to the different proxies. We may ask whether any weighting procedure should be applied at all, and whether or not we should construct composite indicators. We might combine all the proxies in a particular grouping or category to produce a single indicator for, say health and nutrition or dependence on agriculture. Such a procedure is analogous to the construction of indices such as the Human Development Index or a food security index (Downing et al., 2001). We might go even further and construct a single vulnerability index, following the methodology of Moss et al. (2001). The question of weighing is obviously crucial if we are to follow such a procedure.

While the proxies listed in Table 10. have been chosen because they are applicable to all countries, the nature of vulnerability to climate change will differ from country to country, and a given proxy is likely to be more important for some countries than for others. For example, poor health will have a greater negative impact on populations whose livelihoods depend strongly on intensive physical labour in a climate-sensitive area such as agriculture than on populations who depend on less strenuous activities such as tourism or mechanised industry. This context-specificity in the nature of vulnerability means that we must exercise caution in applying uniform weightings of proxies across countries. Nonetheless, certain proxies may be more important than others in determining vulnerability to climate change for many or all countries.

In principal one could assess the relative importance of different vulnerability proxies by examining differences in event outcome between countries exposed to similar hazards. For such a comparison to be meaningful the following conditions would have to be met:

1. there should be a large enough number of countries with similar hazard profiles to make such a comparison meaningful.
2. the period chosen for the comparison should be short enough for vulnerability to remain reasonably constant (otherwise we are examining average vulnerability over time, which makes it difficult to analyse the processes and structure of vulnerability).
3. there should be a sufficiently large number of hazard events during the period of analysis, in order that latent vulnerability be translated into outcome in order to make an outcome-based comparison of vulnerability meaningful.

### 5.4.1. *Validation for small island states and windstorms*

In order for condition (1) to be met, we should choose a subset of countries that are exposed to the same type of hazard(s), and base our comparisons between the different national-level outcome data on a single hazard type. Perhaps the most promising case to choose would be hurricane outcomes for groups of small island states (SISs), as such states are numerous, spatially clustered, exhibit different socio-economic conditions, and are exposed to the same types of hazard, and in many cases affected by the same individual events.

It is difficult to strike a balance between conditions (2) and (3), as discussed in Section 2.3. Socio-economic conditions can change rapidly, particularly in the face of natural disaster (where vulnerability is self reinforcing), political instability, structural reform or changes in global markets. Conversely, a long period may be required in order to capture sufficient hazard events (i) to give a realistic picture of climatic variability and (ii) for a large enough sample of the population to be exposed so that their vulnerability is manifest in terms of hazard outcomes.

The possibility of using outcome data for the purpose of validating vulnerability proxies was investigated using data relating to the number of people killed per decade by windstorms in small island states. A simple hazard index based on the decadal frequency of windstorms as recorded in EM-DAT, scaled by land area containing 99% of the national population (calculated using the CIESIN GPW dataset), was used to compare the hazard profiles of SISs in order to identify "clusters" of states with similar hazard scores. Decadal mortality and hazard data representing the 1970s, 1980s and 1990s were pooled to produce 61 "cases"; a particular SIS represented in both the 1980s and the 1990s would represent two cases, treated as if they are independent, based on the fact that hazard frequency and vulnerability are likely to vary between decades for a given SIS.

For the 61 SIS cases, there is no systematic relationship between mortality outcome and hazard score (Figure 2.4.1). The correlation between hazard score and mortality outcome is negative but close to zero; this relationship, in the opposite direction to that which might be expected, is the result of a small number of cases where low hazard scores are associated with high mortality. The decadal frequency of recorded[2] windstorms for each SIS is generally low (between 1 and 6), and these cases are likely to be the result of single high-impact events.

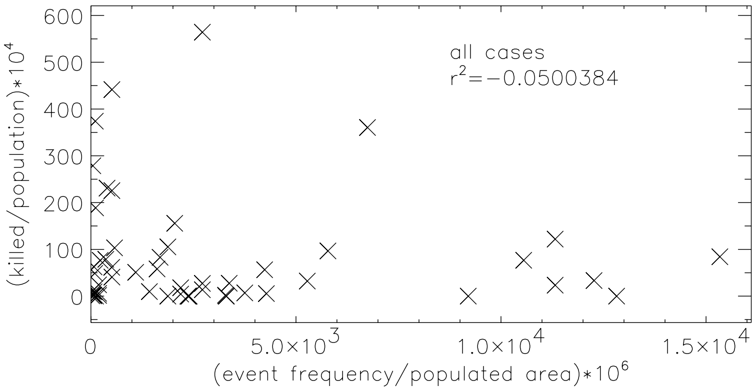


**Figure 2.4.1. Decadal mortality outcomes from windstorms plotted against hazard index for all small island states with available data.**

From Figure 2.4.1. we may tentatively identify three "clusters" of cases based on hazard scores:

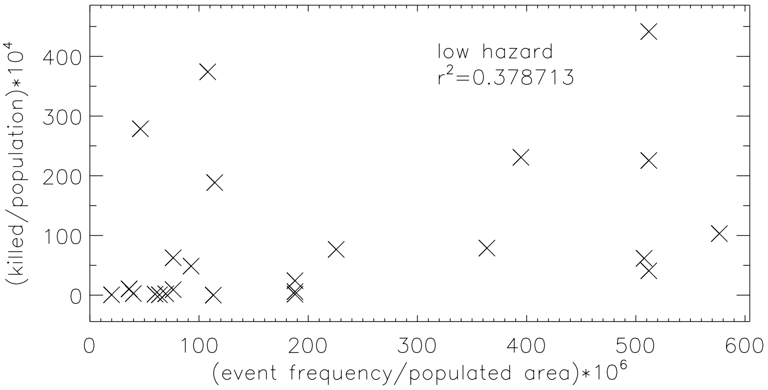
- "low" hazard, with hazard scores below 1000 (25 cases)
- "intermediate" hazard, with hazard scores between 1000 and 7000 (29 cases)
- "high" hazard, with hazard scores above 7000 (7 cases)

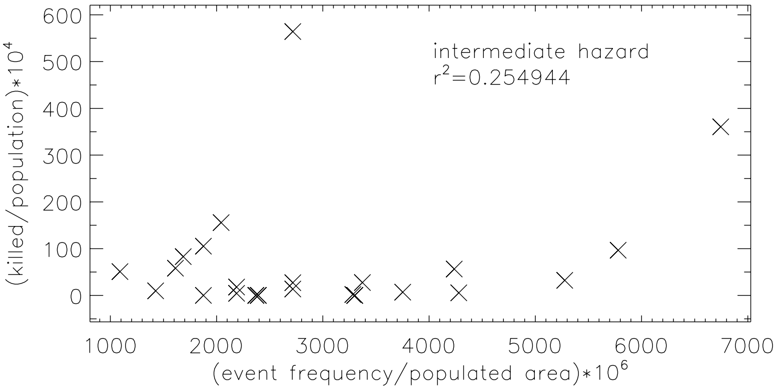
Mortality data are plotted against hazard scores for each category of hazard (low, intermediate and high) in Figure 2.4.2, along with the associated correlation scores, using

---

[2] Only those associated with a disaster as defined in the EM-DAT database are recorded.

data from the 1970s, 1980s and 1990s. While all cases exhibit a positive relationship between hazard score and mortality, these relationships are not statistically significant at the ten per cent level when tested using a simple Monte Carlo procedure (i.e. the probability of that the original correlation will be exceeded when the data are randomised and the correlation recalculated does not fall below 10 per cent). This is not unexpected, given the small number of cases for each hazard category; one or two cases can have a large impact on the value of the correlation coefficient in these circumstances.





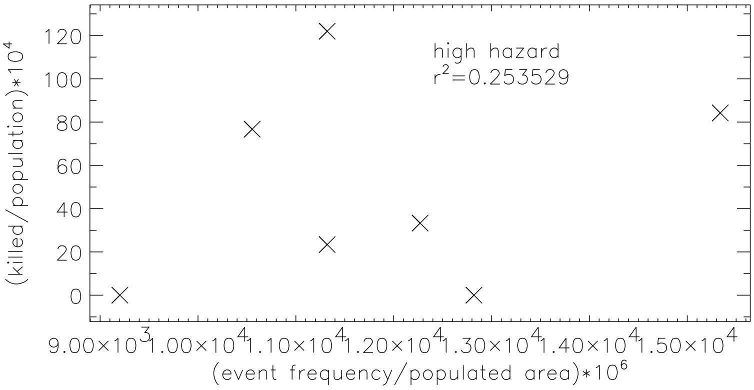


**Figure 2.4.2. Decadal mortality outcomes from windstorms plotted against hazard index for all small island states with available data, separated, from top to bottom, into "low", "intermediate" and "high" hazard, with correlation values.**

The consensus among the research community is that the EM-DAT data are generally not reliable prior to 1980, an opinion supported by the upward trend in recorded disaster event prior to this date, most likely related to improvements in recording practices (see Section 4.3).

Correlations were therefore recalculated using only data from the 1980s and 1990s. Another reason for concentrating on these two decades is that the data used to construct the candidate vulnerability proxies are in many cases not available prior to the 1980s, and some variables are only available for the 1990s (in many cases the late 1990s or the first years of the twenty first century). Using data only from the 1980s and 1990s, the total number of cases representing SISs is 45, with 18, 21 and 6 cases representing low, intermediate and high hazard respectively. The corresponding correlations are given in Table 11. The results reflect those described above, although the relationship between hazard score and mortality outcome borders on significance at the ten percent level in the case of intermediate hazard.

**Table 11. Relationships between hazard frequency, scaled by populated land area, and decadal mortality outcome for small island states and windstorms, using data from the 1980s and 1900s. n represents the number of cases, r the correlation coefficient between the simple hazard index and mortality, and p is the probability that r is exceeded when the data are randomised (based on 1000 random series).**

| Hazard category | n | r | p |
|---|---|---|---|
| all | 45 | -0.03 | 87.8 |
| low (0-1000) | 18 | 0.46 | 31.0 |
| intermediate (1000-7000) | 21 | 0.54 | 10.4 |
| high (7000-15500) | 6 | 0.27 | 94.6 |

The lack of a systematic relationship across all cases may of course be a result of the crude nature of the hazard index, which is not a truly objective measure of hazard, including only those events that caused a significant human impact. Nonetheless, these results do suggest that factors other than hazard frequency play a dominant role in determining outcomes, and that the relationship between hazard frequency and outcome is not likely to be linear, but may be different for different frequency ranges. Of course this simple analysis neglects the severity of individual events, and it would be useful to examine the nature of each individual event that represents the data under investigation, an exercise outside the scope of this project.

The fact that there is no clear relationship between the simple hazard index and the mortality outcome of windstorms for SISs suggests that we might treat all the SISs as a single "cluster", within which outcome is determined by social, economic, political and environmental factors. We can assess the influence of these factors by examining the relationship between variables that represent them (i.e. proxies for vulnerability) and mortality outcome, in the same manner as the relationship between hazard score and mortality outcome was examined above. We can repeat this procedure for low and intermediate hazard cases only; there are too few data in the high hazard category to make such an analysis meaningful. The small number of data in the low and intermediate categories mean that we cannot treat this exercise as a rigorous statistical analysis, but it is potentially instructive to examine relationships between vulnerability proxies and outcome in a semi-quantitative manner. Table 12 below presents correlation values between the individual proxy variables for vulnerability identified in **section 5.3** and mortality outcome from windstorms in SISs, along with the associated probabilities that these values are exceeded when the data are randomised (a low value indicating a stronger statistical relationship than a high value) and the number of cases used in the calculation of the correlation. Results are presented for low and intermediate hazard scores, and also for all cases.

**Table 12. Correlation coefficients (r), probability of exceedance (p) and numbers of cases (n) illustrating relationships between proxy variables and mortality outcomes for small island states and windstorms, for low and intermediate hazard scores and also for all cases. Where no entries are present, there were insufficient data to calculate the correlation coefficient.**

| **hazard:** | **low** | | | **intermediate** | | | **all** | | |
|---|---|---|---|---|---|---|---|---|---|
| variable | r | p | n | r | p | n | r | p | n |
| GDP per capita (US$ PPP) 1985s,95s | -0.27 | 47.9 | 18 | -0.44 | 60.5 | 13 | -0.26 | 68.9 | 38 |
| GINI coefficient, 1985,95 | 0.29 | 91.0 | 7 | 0.55 | 100 | 3 | 0.31 | 70.7 | 10 |
| Debt repayments, % GNI, averaged over decadal periods, 1980s/90s. 1985, 95 in brackets | -0.34 | 53.8 | 16 | -0.56 | 12.9 | 14 | -0.33 | 17.8 | 10 |
| GNI (total, PPP), 1985,95 | -0.31 | 49.8 | 18 | -0.27 | 60.3 | 14 | -0.17 | 52.8 | 39 |
| Health expenditure per capita (US$ PPP) | **-0.64** | **0** | **6** | -0.41 | 90.9 | 6 | -0.16 | 88.6 | 15 |
| Disability adjusted life expectancy | -0.51 | 12 | 41.1 | 0.33 | 95.0 | 9 | -0.34 | 36.9 | 25 |
| Calorie intake per capita | -0.16 | 37.8 | 19 | -0.43 | 47.0 | 16 | -0.22 | 29.8 | 40 |
| AIDS/HIV infection (% of adults) | 0.87 | 16.7 | 7 | - | - | - | **0.86** | **0** | **10** |
| Agricultural production index (1985, 1995) | 0.15 | 61.9 | 20 | -0.32 | 38.2 | 21 | -0.07 | 72.0 | 50 |
| Food price index (annual change averaged over 1981-90 and 1991-99) | -0.28 | 100 | 5 | - | - | - | -0.37 | 90.5 | 6 |
| Life expectancy at birth | -0.49 | 36.3 | 12 | -0.26 | 100 | 3 | -0.50 | 49.2 | 16 |
| Maternal mortality per 100 thousand | 0.58 | 49.7 | 6 | **0.09** | **0** | **5** | 0.27 | 66.1 | 15 |
| Education expenditure as % of GNP, 1980s/90s | 0.13 | 76.9 | 15 | -0.78 | 86.7 | 11 | 0.04 | 87.6 | 32 |
| Literacy rate (% of population over 15), 1980s/90s | -0.32 | 57.5 | 16 | **-0.96** | **0** | **5** | -0.50 | 14.5 | 23 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Education expenditure as % of government expenditure, 1980s/90s | 0.30 | 20.0 | 14 | 0.15 | 77.6 | 10 | 0.27 | 37.8 | 30 |
| Literacy rate (% of 15-24 year olds), 1990s | -0.43 | 17.7 | 10 | - | - | - | -0.46 | 46.7 | 12 |
| Literacy ratio (female to male), 1990s | 0.03 | 98.1 | 10 | - | - | - | 0.00 | 100 | 12 |
| Roads (km, scaled by land area with 99% of population), 1980s/90s | -0.39 | 45.9 | 18 | -0.26 | 61.4 | 10 | -0.30 | 38.7 | 29 |
| Rural population without access to safe water (%), 1980s/90s | -0.16 | 57.1 | 15 | -0.05 | 94.0 | 9 | -0.18 | 55.1 | 27 |
| Population with access to sanitation (%), 1980s/90s | -0.10 | 60.0 | 14 | 0.11 | 92.0 | 9 | -0.06 | 75.0 | 26 |
| Internal refugees (1000s) scale by population | - | - | - | - | - | - | - | - | - |
| control of corruption | - | - | - | - | - | - | -0.38 | 100 | 4 |
| government effectiveness | - | - | - | - | - | - | -0.01 | 100 | 3 |
| political stability | - | - | - | - | - | - | **-0.57** | **0** | **5** |
| regulatory quality | - | - | - | - | - | - | -0.20 | 100 | 5 |
| rule of law | - | - | - | - | - | - | -0.11 | 60.7 | 6 |
| voice and accountability | **-0.54** | **0** | **7** | - | - | - | -0.56 | 12.4 | 9 |
| civil liberties | 0.02 | 95.9 | 20 | **0.34** | **3.9** | **16** | 0.14 | 67.7 | 45 |
| political rights | -0.16 | 69.8 | 20 | 0.16 | 52.5 | 16 | 0.14 | 67.7 | 45 |
| km of coastline (scale by land area), 1990s | 0.37 | 30.9 | 18 | -0.16 | 72.8 | 19 | -0.13 | 53.5 | 42 |
| Population within 100km of coastline (%), 1990s | 0.21 | 65.5 | 12 | 0.24 | 51.8 | 10 | 0.15 | 63.0 | 25 |
| population density | -0.12 | 75.7 | 12 | -0.08 | 98.0 | 12 | -0.18 | 54.8 | 28 |
| Agricultural employees (% of total population) (1980, 1990) | -0.12 | 62.1 | 10 | **0.90** | **0** | **5** | **0.53** | **0** | **17** |
| Rural population (% of total) , 1980s/90s | **0.62** | **0.9** | **20** | 0.23 | 19.9 | 22 | **0.43** | **4.0** | **51** |
| Agricultural employees (% of male population) (1980, 1990) | 0.09 | 55.8 | 10 | **0.89** | **0** | **5** | **0.45** | **0** | **17** |
| Agricultural employees (% of female population) (1980, 1990) | -0.25 | 40.2 | 4 | **0.91** | **0** | **5** | **0.54** | **0** | **17** |
| Forest change rate (% per year), 1980s/90s | -0.34 | 40.3 | 10 | **0.68** | **0.9** | **12** | -0.03 | 88.2 | 28 |
| Protected land area (%), 1980s/90s | -0.23 | 67.6 | 16 | -0.10 | 85.0 | 18 | -0.12 | 79.8 | 39 |
| Groundwater recharge per capita, 2000 | -0.11 | 96.5 | 6 | - | - | - | -0.07 | 90.7 | 8 |
| Percent forest cover, 1980s/90s | **0.62** | **0** | **20** | -0.15 | 65.8 | 19 | 0.42 | 14.0 | 48 |
| Water resources per capita, 2000 | -0.04 | 93.7 | 10 | - | - | - | -0.05 | 88.0 | 15 |
| Unpopulated land area | -0.10 | 91.2 | 12 | 0.20 | 67.3 | 12 | 0.14 | 71.3 | 28 |
| R&D investment (% GNP) | - | - | - | - | - | - | **-0.37** | **0** | **3** |
| Scientists and engineers in R&D per million population | - | - | - | - | - | - | 0.01 | 100 | 4 |

The results presented in Table 12. above indicate there is little correspondence between many of the posited vulnerability proxies and mortality outcomes. The probability that the correlation is exceeded when randomised data are used is less than 10 per cent for the following variables, for at least one category of hazard:

1. health expenditure per capita (*)
2. AIDS/HIV infection
3. maternal mortality (*)
4. literacy (per cent of those over 15) (*)
5. political stability (*)
6. voice and accountability (*)
7. civil liberties
8. agricultural employees, total
9. agricultural employees, male
10. agricultural employees, female
11. rural population
12. forest change rate
13. per cent forest cover
14. investment in research and development (*)

Correlations for variables marked with an asterisk were based on fewer than 10 pairs of data values. For many variables, a low probability that the correlation for one hazard category is exceeded by random data is offset by a very high probability of exceedance for other hazard categories. Such results suggest that we cannot generalise from individual groups of SISs, or that some of the correlations may be spurious. Nonetheless, the direction of the relationship between outcome and the fourteen variables above (and many variables that exhibit a weaker relationship with outcome) is as expected, with the exception of civil liberties. Per cent forest cover, rural population and people employed in agriculture do appear to yield reasonably robust results. Coastal forests are likely to play a significant role in protecting SISs from the impacts of storm surges.

### 5.4.2. *Validation using all countries and aggregated mortality data*

Although the proxy variables representing vulnerability have been chosen for their general applicability to a wide range of circumstances, their relative importance will vary according to hazard type and social, economic, political, geographical and environmental context. While the above results suggest that many of the variables have little predictive value for SISs (issues of data coverage and reliability notwithstanding), we cannot necessarily generalise these results to all countries, where different contexts may result in the relative importance of the indicators being different. Neither can we treat the proxy variables as independent, and the way in which the different factors they represent interact with one another may vary significantly across countries. Interactions between the different factors represented by the above variables is likely to be as important in determining vulnerability as the individual factors themselves.

As we are ultimately concerned with the vulnerability of countries to the whole range of hazards that may be associated with future climate change, it makes sense to base historical validation on the study of a variety of climate hazards. We might undertake validation exercises based on separate assessments of relationships between vulnerability proxies and outcome data for individual hazard types in turn, attempting to choose countries with similar hazard profiles in each case. However, we would be likely to face greater difficulty in defining country clusters than in the above case of SISs and wind storms, and the numbers of cases in these clusters would probably be smaller than in the SIS example. Such an exercise would thus be deeply flawed.

Alternatively we might postulate a hypothetical hazard index that captures national exposure to a range of climate hazards, and that would be comparable across countries. The resulting hazard scores would explain a component of outcome (whether measured in terms of mortality, morbidity or economic impact, for example). However, variations in hazard score would not entirely explain variations in outcome aggregated over time. Differences in outcome not related to differences in the hazard index would be the result of differences in the structural factors constituting societies' inherent or social vulnerability, and represented by the proxy variables identified above. We may therefore examine relationships between proxy variables representing these components, and outcome data, while recognising that these components do not represent a complete predictive description of outcome, which is representative of risk rather than vulnerability. Such an approach is in principle one of examining all the determinants of outcome except one, namely a country's hazard profile.

The procedure employed above for SISs and wind storms, in which outcome data were correlated with various proxy variables representing vulnerability, was repeated using aggregated decadal outcome data from all climate hazard events recorded in EM-DAT, for all countries for which data were available. The results are presented in Table 13.

**Table 13 (overleaf). Correlation coefficients (r), probability of exceedance (p) and number of data (n) illustrating relationships between proxy variables and mortality outcomes for all climate related disasters aggregated by decade, for all countries for which data are available. Where the periods represented are stated in brackets in the first column, individual years indicate that the data were annual (or 'point') data, while decades indicate that the data used were annual data averaged over a decade, or representing change over a decade where the variable description indicates this. Time periods in italics were not used in the analysis, but are represented by data in the indicators dataset. The second figure in the final column represents the number of cases N in the combined data sets (including missing data) for each separate correlation analysis. Where two decades are represented, the number of countries represented by the variable in question (including missing data) is N/2.**

| **Variable** | **r** | **p** | **n/N** |
|---|---|---|---|
| GDP per capita (US$ PPP) (1985, 1995, *1980s, 1990s*) | -0.14 | 12 | 272/414 |
| GINI coefficient (1985, 1995, *various*) | 0.16 | 15 | 199/300 |
| Debt repayments (% GNI, averaged over decadal periods) (1985, 1995, *1980s, 1990s*) | -0.05 | 56 | 222/414 |
| GNI (total, PPP) (1985, 1995, *1999*) | -0.5 | 58 | 278/414 |
| Health expenditure per capita (US$ PPP) (1995) | -0.19 | 21.4 | 134/207 |
| Disability adjusted life expectancy (2000) | -0.05 | 64.3 | 163/191 |
| Calorie intake per capita (1980s, 1990s) | -0.18 | 3 | 267/468 |
| AIDS/HIV infection (% of adults) (2001) | 0.00 | - | 130/173 |
| Food production index (annual change averaged over 1981-90 and 1991-99) | -0.01 | 90 | 141/414 |
| Food price index (annual change averaged over 1981-90 and 1991-99) | -0.01 | 90.7 | 141/414 |
| Life expectancy at birth (1995) | -0.21 | 7.7 | 148/173 |
| Maternal mortality per 100 thousand (1985) | 0.33 | 0.5 | 109/173 |
| Education expenditure as % of GNP (1985, 1995) | -0.13 | 23 | 250/346 |
| Literacy rate (% of population over 15) (1985, 2000) | -0.24 | 1.1 | 221/346 |
| Education expenditure as % of government expenditure (1985, 1995) | -0.09 | 29.4 | 230/346 |
| Literacy rate (% of 15-24 year olds) (2000) | -0.35 | 0.01 | 116/173 |
| Literacy ratio (female to male) (2000) | -0.20 | 9.7 | 115/173 |
| Roads (km, scaled by land area with 99% of population) (1985, 1995) | -0.09 | 25.4 | 281/414 |
| Rural population without access to safe water (%) (1990, 2000) | -0.68 | 67.3 | 69/234 |
| Population with access to sanitation (%) (1990, 2000) | -0.39 | 0.01 | 67/234 |
| Internal refugees (1000s) scale by population (2000) | -0.45 | 42.6 | 12/173 |
| control of corruption (1998) | -0.22 | 31.5 | 46/175 |
| government effectiveness (1998) | -0.29 | 9.5 | 53/175 |
| political stability (1998) | -0.08 | 49.6 | 63/175 |
| regulatory quality (1998) | -0.24 | 12.5 | 80/175 |
| rule of law (1998) | -0.36 | 11.1 | 57/175 |
| voice and accountability (1998) | -0.36 | 3.8 | 70/175 |
| civil liberties (1985, 1995) | 0.17 | 5.1 | 303/442 |
| political rights (1985, 1995) | 0.15 | 7.6 | 303/442 |
| km of coastline (scaled by land area) (1990) | -0.03 | 83.5 | 147/207 |
| Population within 100km of coastline (%) (1995) | 0.07 | 53.4 | 166/234 |
| population density (1995) | -0.02 | 88.6 | 170/225 |
| Agricultural employees (% of total population) (1980, 1990) | 0.12 | 23.9 | 230/414 |
| Agricultural employees (% of male population) (1980, 1990) | 0.13 | 22.0 | 230/414 |
| Agricultural employees (% of female population) (1980, 1990) | 0.12 | 26.2 | 233/414 |
| Rural population (% of total) (1985, 1995) | 0.10 | 18.3 | 319/414 |
| Agricultural production index (1985, 1995) | -0.03 | 66.7 | 309/468 |
| Forest change rate (% per year) (1985, 1995) | -0.04 | 75.3 | 142/468 |
| Protected land area (%) (1980, 1990, *2000)* | 0.00 | 100 | 286/468 |
| Groundwater recharge per capita (2000) | -0.02 | 85.7 | 131/234 |
| Water resources per capita (2000) | -0.04 | 78.2 | 150/234 |
| Unpopulated land area (1995) | -0.03 | 77.3 | 170/224 |
| R&D investment (% GNP) (1995) | -0.03 | 85.8 | 63/173 |
| Scientists and engineers in R&D per million population (1995) | -0.18 | 29.7 | 79/173 |

The following variables are all associated with correlation coefficients (with decadal mortality outcome) that have a probability of less that 10 per cent of being exceeded when the data are subjected to a randomisation procedure. The values are presented in ascending order of probability of exceedance (inversely related to the strength of the statistical relationship).

1. population with access to sanitation
2. literacy rate, 15-24 year olds
3. maternal mortality
4. literacy rate, over 15 years
5. calorie intake
6. voice and accountability
7. civil liberties
8. political rights
9. government effectiveness
10. literacy ratio (female to male)
11. life expectancy at birth

These results emphasise health status, governance and education. Calorie intake and sanitation are predictive of health status, while life expectancy and maternal mortality are diagnostic of health status and of the efficacy of health care. All three measures of literacy exhibit significant correlations with mortality outcomes, although by far the most significant correlation is between mortality outcome and literacy among 15-24 year olds. The governance indicators emphasise people's ability to participate in the political process. The probability that the correlation coefficient is exceeded when randomised data are used is less than 5 per cent for variables 1 to 6 above.

The probability of exceedance is between 10 and 20 per cent, indicating a weaker but non-negligible statistical relationship, for the following variables:

- GDP
- Gini
- regulatory quality
- rule of law
- rural population as a per cent of total,

while health expenditure per capita, educational expenditure as a per cent of GDP, road density and per cent of population employed in agriculture are associated with probabilities of exceedance slightly above 20 per cent. While these relationships are weak they should not be ignored given the mis-match between the periods represented by the vulnerability and mortality data, as discussed below.

Even where statistically relationship are very weak, the direction of the relationship between outcome and the vulnerability proxies is generally what might be expected from an intuitive understanding of vulnerability, except where the correlations are near zero.

These results are promising, especially when we consider that the proxy variables do not generally represent the entire span of the periods over which the mortality outcome data are calculated. For example, the KKZ governance data all represent 1998, towards the end of the period represented by the outcome data. We might expect the results to underestimate the strength of any relationship between governance and outcome, particularly if there are a number of countries where high mortality was experienced in the early or mid 1990s as a result of the occurrence of particular severe climate hazards, and where structures and institutions of governance subsequently evolved significantly over the course of the 1990s. The fact that we find a considerable number of variables to be strongly correlated with mortality outcomes suggests that there is a high degree of temporal autocorrelation in the vulnerability proxy data, suggesting that the assumption of relative constancy in socio-economic and political conditions over the course of a decade is not entirely unrealistic. Of course there are numerous examples of countries that have experienced dramatic changes in the socio-political and economic landscape. While their number is not sufficient to completely undermine the above analysis, such discontinuities, and non-catastrophic but still significant societal change, may still obscure important relationships between the vulnerability proxy data and the outcome data. While we may interpret the statistically strong relationships above as indicating that the proxy in question does capture elements of vulnerability, we should not completely dismiss those proxies where relationships are statistically weak. This assessment should therefore be seen as a first step in identifying useful proxies for vulnerability, indeed in identifying some of the most important such proxies, on which we may build with further analyses and systematic comparisons using different case studies.

### 5.5. Constructing indicators

The problems associated with weighting and aggregating the proxy data to produce composite indicators were discussed briefly at the beginning of Section 5.4. The different approaches that might be adopted in constructing indicators are outlined below.

1. Constructing a single indicator by aggregating all relevant proxies

This approach is superficially attractive, as it allows us to rank countries and to identify the "most vulnerable" countries. It might be of use to international agencies and donors wishing to prioritise adaptation assistance to the most vulnerable nations, but it tells us nothing about the structure and causes of vulnerability. It might also lead to important areas of vulnerability being neglected, as countries that do not score highly in terms of the vulnerability index are assumed to be able to cope with climate change. There is also the issue of how any such aggregation is carried out: should we average all the proxy data, and if so should we weight the various proxies? If weightings are used, how are they to be calculated? We might choose only those proxy data exhibiting high correlations with outcome (section 5.4.), and base the weightings on the magnitude of the correlation or on the level of significance of the correlation (or a combination of both). However, this approach ignores the fact that the relative importance of different proxies will vary across countries; the correlation and significance data represent a generalisation of the importance of various causal factors across a large number of cases. We should also recall that the originators of certain data (Kaufmann et al., 1999b) caution against averaging or standardising these data, and suggest that because of the errors in the data they are most appropriate for assigning countries to groups, rather than comparing individual countries.

2. Constructing a single indicator by defining country groupings
An alternative way of constructing a single indicator would be to define a number of categories representing different levels of vulnerability (such as low, intermediate and high). For each proxy variable used to represent vulnerability to climate change, the data could be assigned to these categories. Each category could be assigned a score (for example 1 for low, 2 for intermediate and 3 for high), and the overall vulnerability of a country could then be calculated by summing the scores for individual proxies. This approach would circumvent the problems associated with averaging or standardising the proxy data themselves, but would only allow us to say whether a country was in a particular groups (in this case one of nine), as opposed to giving us unique values enabling comparisons between individual countries.

3. Constructing separate indicators representing different elements of vulnerability
Procedures 1 and/or 2 above could be carried out for the various categories of vulnerability proxies defined in section 5.3., yielding a set of nine indicators representing economic factors (EC), health and nutrition (HN), education (EDU) and so on. Different elements of vulnerability could then be examined separately, and these separate indicators would tell us on which areas a country needed to concentrate in order to reduce its vulnerability.

4. Vulnerability profiles
Depending on the number of proxies used, either the individual proxies or the nine indicators constructed from them (described in 3 above) could be presented for individual countries graphically in terms of vulnerability profiles (Downing et al., 2001). Vulnerability profiles enable a quick assessment of a country's strengths and weaknesses in terms in terms of the structural causes of vulnerability, and tell us where to concentrate in terms of vulnerability reduction and capacity building.

Simple aggregation (Approach 1) was rejected for the reasons outlined above. Instead, a combination of Approaches 1 and 2 was adopted to construct a vulnerability index based on the 11 proxy variables that were significantly correlated with mortality outcome at the 10 per cent level. For each of the 11 proxies, the range of data was divided into quintiles, and each country was assigned to a quintile. Where the correlation with mortality outcome was positive, a country in the bottom quintile scored 1, and a country in the top quintile scored 5 for the variable in question. Where the correlation with outcome was negative, the scoring system was reversed. Each country was thus assigned a score of 1 to 5 for each variable, depending on the value of that variable for the country in question, with a score of 1 representing low vulnerability and a score of 5 representing high vulnerability. These scores are presented in Appendix 1. An average score was calculated across all 11 variables, and the result multiplied by 10 to give a score from 10 to 50.

## 5.6. Vulnerability scores

The aggregated vulnerability scores, calculated as described in section 5.5 above, are presented in Appendix 2. Recorded alongside the scores is the number of variables from which each score was calculated - data representing all 11 variables were not available for all countries.

Three countries are represented by the maximum possible score of 50: Afghanistan, Democratic republic of Congo, and Somalia. Angola scores 48, while Burundi and Iraq score 43. All these countries have been severely affected by armed conflict, resulting in extreme adverse effects on governance structures and general physical and social infrastructure.

Of the 45 top scoring countries, all but 12 are in sub-Saharan Africa. Of the 22 highest scoring countries, only two are outside sub-Saharan Africa. This is not surprising when we consider the indicators used in the analysis. The isolation and poverty of many sub-Saharan populations means that they have little access to healthcare, and are highly food insecure. In addition to problems of corruption and representation, the state and its institutions are effectively absent from many areas of sub-Saharan Africa (a mixed blessing in some cases, given that the state may hinder as well as facilitate adaptation). Many of sub-Saharan Africa’s problems are related to poverty at the household level and lack of resources at the local and national levels, and these results demonstrate that the 11 variables chosen capture poverty-related vulnerability, even though economic indicators are not explicitly represented. The results also suggest that the economic indicators assessed are too crude to represent vulnerability (at least in terms of mortality from climate-related disasters). It is not necessarily poverty *per se* that makes people vulnerable, rather it is factors associated with poverty such as corruption, poor infrastructure and lack of access to resources.

While the vulnerability of sub-Saharan African countries is captured in the above analysis, small island states are not systematically represented by high scores. This is not particularly surprising given the nature of the eleven indicators used - they do not include any measures of the geographical factors that are especially important in determining the vulnerability of SISs. Furthermore, of all the indicators employed in the analysis, very few exhibited strong and systematic statistical relationships with mortality when the validation assessment was carried out for SISs and the principal hazard they face, windstorms. Of course we might conclude that the vulnerability of SISs has been overestimated, particularly in comparison with countries in sub-Saharan Africa. However, SISs will be particularly vulnerable to sea level rise and hazards covering a large area because of their small size, which will mean a high percentage of their population is likely to be exposed to a single event, and also that there is little scope for relocating settlements and economic activity in less exposed areas. Indicators that capture these factors will be less important for the majority of countries, which cover greater areas and are not bordered on all sides by ocean, and so will not be strongly correlated with mortality when validation is based on an analysis representing all countries. Any statistical signal arising from the SISs will be swamped by that large number of cases where indicators appropriate for SISs only are not relevant.

Several lessons may be drawn from these results:

1. These indicators are biased against SISs in that they appear to underestimate their vulnerability.
2. Generic indicators should only be used to draw general conclusions about the distribution of vulnerability at the global level: while they may be used for determining whether a country has a high, intermediate or low vulnerability, they are not appropriate for comparing the vulnerabilities of individual countries.
3. The vulnerabilities of countries facing certain highly specific circumstances are likely to be misrepresented by generic indicators, and such groups should be identified and treated separately.

## 6. MODELLING THE PROCESS OF ADAPTATION

This report confirms the view of previous reviewers that study of the determinants of vulnerability and the related process of adaptation is at an early stage. Although there is an expanding body of work on this subject, much of the research is case study-based. These case studies highlight particular factors that have proved of importance in specific situations, and various common threads have emerged, but a generalised theory of adaptation has yet to emerge.

Indeed, some would argue that the capacity to adapt, that most fundamental aspect of human behaviour, is, by its opportunistic nature, so situation-specific and dynamic that predictive understanding may be extremely difficult to achieve. It may well prove impossible to model the adaptive process from ‘first principles,’ with the science of adaptation limited to description and eschewing prediction, an interesting philosophical dilemma.

Setting aside for now the question of any ultimate limit on the development of adaptive theory, how can the process of adaptation be incorporated in the current generation of integrated climate models? This is a critical question as, without explicit handling of adaptation, severe criticism can be levelled at the impact component of any integrated modelling suite.

The process of adaptation can offset impacts, negate them completely or even reverse their sign, turning the threat of adverse consequences into a beneficial opportunity or, in the case of mal-adaptation, turning a minor crisis into a catastrophe. To attempt to assay the scale of the climate problem, or the efficacy of proposed emissions control strategies, without explicit consideration of the adaptive process is launch into flight without wings. Yet the absence of any generalised theory, permitting modelling from first principles, or even validated evidence of semi-empirical relationships, renders modelling of the adaptive process problematic except in severely constrained circumstances[3].

Is there a generalised approach that would enable adaptation to be incorporated into an integrated modelling framework? One possibility is prescriptive in nature. Taking the analogy of emissions control, a suite of targets for adaptive performance could be specified within the model framework, with no explicit simulation of the policies, measures and other developments that might facilitate adaptation and enable any particular target to be achieved.

From the perspective of the climate negotiations, again drawing on the analogy of emissions control, this may well be the only way in which the issue of adaptation can be dealt with effectively without infringing national sovereignty (nations would be free to meet targets in whatever way they considered appropriate).

To illustrate this approach, consider the highly idealised case of a single community confronted by the threat of an adverse impact from a single source (say, a coastal community threatened by sea-level rise). The community is homogenous, with no diversity of income, access to resources, etc. In other words, all members of the community have the same adaptive capacity or potential.

We first develop the simplest model that deals with adverse impacts alone. Here, the final impact after adaptation has taken place will be a function of the exposure of the community, that is, the potential impact in the absence of any adaptive response (refs),[4] and the response of the community to the perceived threat which we consider, following Kelly and Adger (2000), to be directly related to the degree of vulnerability of the community. Kelly and Adger (2000) define vulnerability as a measure of the capacity of a community to respond to external stress.

We adopt the formulation that, at time t,

$$I_t = (c_t - 1)X_t \qquad c_t \geq 1$$

where I is the final impact, X is the exposure (an estimate of the impact prior to any adaptive response) and c is a dimensionless scaling factor, the coping capacity, that can alter the scale of a potential impact. In this simple model, we restrict c to a positive value so the sense of the impact (adverse or beneficial) cannot be altered. The coping capacity is one aspect of the adaptive capacity and inversely related to vulnerability. I and X may be an estimate of area flooded, loss of GDP, mortality level, etc.

---

[3] It is, of course, possible to build a model of a specific adaptive response, the construction of a sea wall, for example, but this is only possible in highly particular circumstances and will, most likely, only simulate a subset of relevant factors (physical but not social, economic but not institutional, etc).

[4] This use of exposure here corresponds to the combined IPCC concepts of exposure and sensitivity (see section 2.2.2), a distinction that we find difficult to justify except in very specific circumstances.

In our simple case, $c = 2$ indicates the rather unlikely case of no adaptive response. $c = 1$ indicates that the impact is completely negated. A value of c greater than 2 is indicative of mal-adaptation, a response that aggravates the potential impact.

The simplest approach to modelling this process, paralleling the political approach to the issue of vulnerability suggested above, would be to set targets for vulnerability reduction (improvement in coping capacity) over time. These targets could be phrased in terms such as "an enhancement of coping capacity commensurate with a 50% reduction in final impact by the year 2050 then negation of impact by 2100," corresponding, in our highly simplified case, to a target of $c_{2050}= 1.5$ and $c_{2100} = 1$.

We can take this approach further and add detail to our simple simulation. Consider our coping capacity, c. What determines how effective any adaptive response is? What is c a function of? On the basis of previous work, it is possible to identify various factors that may be important. There is the potential for coping. It may be that nothing can realistically be done to avert sea-level rise impacts given the local geography. Access to timely, credible and reliable information must be a significant contributor (Kelly et al., 2001). Misleading or delayed information may well result in mal-adaptation. Then there is the issue of empowerment. Are people able and willing to act whatever the potential for coping?

So, dropping the time dependence, we might develop a more sophisticated formulation where

$$c = f(K_c, E_c, P_c)$$

where K is some measure of knowledge, or access to information, relevant to the process of coping, E is a measure of empowerment and P is a measure of the coping potential.

As understanding improves, each of these components can be simulated in an increasingly sophisticated and, it is hoped, realistic fashion. Knowledge is a function of, amongst other things, the availability of information, the readiness of the community to accept that information, including the process of amplification or distortion that may occur as information is acquired and transmitted on[5], and the reliability of that information (Kelly et al., 2001). Empowerment is a function of many factors, from the individual through the communal to the institutional and political (REF NEEDED). Coping potential is closely related to, if not synonymous with, access to resources in the most general sense (financial, human, natural, etc), following Sen (1981). Access to resources is itself a function of the existence of appropriate resources, of poverty and inequality, levels of empowerment, institutional constraints on resource access, and so on.

Even if understanding of the processes that shape vulnerability is not at the stage where most of these relationships can be modelled explicitly, these relationships do suggest policies and measures that might be adopted to facilitate adaptation (cf. Kelly and Adger, 2000). In our simple modelling framework, prescriptive targets could be set for K, E and

---

[5] An exaggerated view of a community's sensitivity could result in mal-adaptation, with $I_t$ greater than $X_t$.

P and the sensitivity of the outcome, the ultimate impact, assessed in the same way that sensitivity to emissions control targets or scenarios is examined. In come cases, understanding may well be sufficient to enable assessment, at least in broad terms, of the credibility of the various adaptation targets that are considered. Again, the analogy with the handling of emissions control in both the integrated modelling and political context is clear.

What are the limitations of this simple framework?

Most importantly, we have neglected a critical component of the climate issue. Impacts may be adverse or beneficial and, indeed, an adverse impact may be transformed into a beneficial one through the process of adaptation. To promote an optimal outcome, a non-linear framework is required that rewards the amplification of positive consequences whilst favouring the reduction of negative impacts.

We modify the framework outlined above by introducing the concept of evolution. Now, the adaptive response may take the form of coping, resulting in a return to previous conditions, or evolution, leading to a new state. We define e as a measure of the evolutionary capacity, the degree to which positive outcomes can result from beneficial or adverse impacts.

We then deal separately with adverse and beneficial impacts.

As before, for adverse impacts,

$$I_t = (c_t - 1)\, X_t$$

In a resilient community, $c_t$ will be close to one. In all situations, $c_t \geq 1$.

There will be a transitional point where coping becomes evolution, i.e. X moves from negative to positive (or *vice versa* depending on how these variables are defined). The addition of a random perturbation to the right-hand side of the equation would create the potential for that transition, mirroring, for example, the effects of inherent variability in natural and social systems if not natural selection’s random trigger.

For beneficial impacts, then,

$$I_t = e_t X_t$$

In a dynamic, evolving community, $e_t$ will be greater than 1. In all situations, $e_t \geq 0$.

In both cases, it may be useful to attach a trajectory or time constant to the coping and evolutionary processes, indicating that such processes have a multi-year timespan and a characteristic pattern of development and decay. Clearly, without such a constraint, the evolutionary formulation would result in a totally unrealistic outcome.

From a conceptual point of view, the value of this framework is that we are defining two distinct adaptive processes: an evolutionary process that maximises the benefits of positive impacts; and a second, resilient process of coping that minimizes the effects of negative impacts and preserves the *status quo*. The adaptive capacity can thus be redefined as a function of the coping capacity and the evolutionary capacity. In the context of the present project, the vulnerability indicators that have been identified, directly related to coping and evolutionary or adaptive capacity, could be incorporated into an integrated model on a semi-empirical basis as part of a parameterisation of what might be considered processes beyond the societal resolution of the model.

Two particular questions arise.

First, can we distinguish between the potential for adverse impacts and for beneficial consequences? The answer must be that, at the level at which impact processes are modelled, it should be possible. For example, the impact of the sea-level rise on a community will be complex, determined by the cumulative effects of increased risk of flooding, saltwater intrusion, etc. And, without a doubt, an adverse impact on one member of a community may be the opportunity of a lifetime for another. But by breaking down a generalised impact such as sea-level rise to its component parts and considering differential effects across the community, it should be possible to determine the sense of the potential consequences. From the point of view of modelling, it is the initial sense of the impact (or even the initial perception of the sense of the impact) that has to be defined. From then on, the processes of coping and evolution will determine the ensuing profile over time.

The second, related, question concerns the distinction between a coping response and an evolutionary response. Traditionally, a distinction between coping and adaptation has been drawn on the grounds of timescale, with coping generally describing the short-term response to the occurrence of discrete hazards or extreme events, often on the synoptic to seasonal timescale) and adaptation use to describe the slower response to long-term multi-year or decadal trends (including the changing frequency of short-lived events). Here, we argue that the response to stress *on any timescale* is composed of two distinct responses: coping, minimising adverse effects, and what we term evolution, taking advantage of beneficial opportunities. Heightening a sea-dyke constitutes coping. A related evolutionary response might be to make oneself available for hire as a labourer in a prompt and timely fashion when it becomes clear that dykes must be strengthened! From this perspective, the political challenge of climate change is one of empowerment, to ensure that the great majority of the world's population are able to evolve as climate continually alters, rather than cope with ever-changing stress – a world of winners rather than of victims and losers.

## 7. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This project has led to significant advances in the field of vulnerability and adaptation work. The development of a conceptual framework enabling researchers to relate the concepts of vulnerability, risk and adaptive capacity to one another should reduce the current high level of confusion over the use of terms that is the result of a general lack of communication between those working the fields of climate change and natural hazards and disaster management, at least at the academic level. The conceptual framework also provides a context within which indicators may be developed, and should enable researchers to be more clear as to what they are developing indicators for.

The work on outcome-based indicators of risk demonstrates that disaster data may be used to help our understanding of risk and vulnerability, although improvements in such data are desirable. Outcome data may be used as a useful tool in assessing the validity of proxies for risk and vulnerability.

The project results suggest that health, education, and particularly governance indicators, can provide us with a reasonable assessment of vulnerability to climate hazards, at least in terms of mortality related to discrete extreme events. A number of health, education and governance proxies exhibit a strong relationship with mortality outcomes from climate related disasters when tested using date from the 1980s and 1990s. These proxies can be used to construct indicators of vulnerability using a variety of approaches. Construction of composite indicators by averaging should be treated with caution; a better approach is to examine whether countries fall into categories of low, intermediate or high vulnerability for a variety of proxies in turn, and to assign scores for these categories which may then be averaged to produce a vulnerability index. Disaggregated indices for different elements of vulnerability can be useful than a single index as they provide information on the structure of vulnerability.

The project does illustrate the limitations of generic national-level indicators. While certain factors are important in a wide range of national contexts, certain countries experience very specific processes that cause vulnerability, and generic indicators will underestimate the vulnerability of such nations. The indicators employed here underestimate the vulnerability of small island states, due in large part to the validation process used to select a small number of indicators from a wide range of possible indicators. It is therefore vital that global assessments intended to identify vulnerability "hot spots" and target capacity building assistance are not based solely on generic indicators. Rather, generic indicators should be used as a first step in assessing vulnerability at the national scale.

Future work should build upon analyses presented here by examining case studies in order to determine to what extent the results obtained here may be generalised. While indicators have their role to play, they can only capture the most general aspects of vulnerability when applied at the national level. It is, therefore, important to develop our understanding of vulnerability by examining how it arises in a variety of contexts, paying attention to the relative importance of various social, economic, political, geographic and environmental factors in different countries, and also to the hazard-specific nature of vulnerability. The proposed modelling framework warrants exploration through a trial implementation. This may be best achieved through a PhD studentship.

## References

Adams, J., 1995. *Risk*, University College London Press, London, pp 228.

Adams, W. M. and Infield, M., 2003. Who is on the gorilla's payroll? Claims on tourist revenue from a Ugandan national park, *World Development* 31 (1), 177-190.

Adams, A. M., J. Cekan, and R. Sauerborn. 1998. Towards a conceptual framework of household coping: Reflections from rural West Africa. *Africa* 68 (2):263-283.

Adger, W. N., Khan, S. R. and Brooks, N, 2003. Measuring and enhancing adaptive capacity, *Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change*, UNDP.

Adger, W. N. and Brooks, N., 2003. Does environmental change cause vulnerability to natural disasters? In Pelling (ed.), *Natural Disasters and Development in a Globalising World*, Routledge, London19-42.

Adger, W. N., Huq, S., Brown, K., Conway, D. and Hulme, M., 2003. Adaptation to climate change in the developing world. *Progress in Development Studies* 3, 179-195.

Adger, W. N., Huq, S., Brown, K., Conway, D. and Hulme, M., 2002. Adaptation to climate change: Setting the Agenda for Development Policy and Research. Tyndall Centre for Climate Change Research Working Paper 16.

Adger, W. N. 2000. Social and ecological resilience: are they related? *Progress in Human Geography* 24(3): 347-364.

Adger, W. N., 1999. Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. *World Development* 27 (2), 249-269, 1999.

Adger, W. N. and Kelly, P.M. 1999. Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change* 4, 253-266.

Adger, W.N. 1996. *Approaches to vulnerability to climate change.* Global Environmental Change Working Papers. Norwich: Centre for Social and Economic Research on the Global Environment.

Allen, K., 2003. Vulnerability reduction and the community-based approach, in Pelling (ed.), *Natural Disasters and Development in a Globalising World*. Routledge, London, 170-184.

Anderson, M.B. and Woodrow, P.J. 1991. Reducing vulnerability to drought and famine: developmental approaches to relief. *Disasters* 15, 43-54.

Augusti, G, Borri, C and Niemann, H-J. 2001. Is aeolian risk as significant as other environmental risk? *Reliability Engineering and System Safety* 74, 227-237.

Bell, S. and Morse, S. 1999. *Sustainability Indicators. Measuring the Immeasurable*. Earthscan, London.

Blaikie, P., Cannon, T., Davis, I and Wisner, B., 1994. *At Risk: Natural Hazards, People's Vulnerability, and Disasters*. London, Routledge.

Bohle, H.G., Downing, T.E. and Watts, M.J. 1994. Climate-change and social vulnerability - toward a sociology and geography of food insecurity. *Global Environmental Change-Human And Policy Dimensions* 4, 37-48.

Bowen, R. E. and Riley, C., 2003. Socio-economic indicators and integrated coastal manangement. *Ocean and Coastal Management* 46, 299-312.

Bowen, R. E. and Riley, C., 2003. Socio-economic indicators and integrated coastal manangement. *Ocean and Coastal Management* 46, 299-312.

Brooks, N. and Adger, W. N., 2003. Country level risk measures of climate-related natural disasters and implications for adaptation to climate change. Tyndall Centre Working Paper 26: http://www.tyndall.ac.uk/publications/working_papers/wp26.pdf).

Burton, I., Huq, S., Lim, B., Pilifosova, O. and Schipper, E. L., 2002, From impacts assessment to adaptation priorities: the shaping of adaptation policies *Climate Policy* 2, 145-159.

Burton, I., Kates, R. W. and White, G.F. 1993. The Environment as Hazard, New York, The Guildford Press.

Campbell, D.J. 1999. Response to drought among farmers and herders in southern Kajiado District, Kenya: a comparison of 1972-1976 and 1994-1995. *Human Ecology* 27, 377-415.

Cannon, T. 2002. Gender and climate hazards in Bangladesh, *Gender and Development*. 10 (2), 45-50.

Cash, D. W. and Moser, S. C., 2000. Linking global and local scales: designing dynamic assessment and management processes. *Global Environmental Change* 10(2), 109-120.

Chambers, R. 1989. Vulnerability, coping and policy. *IDS Bulletin* 20,1-7.

Clark, W. C., Jäger, J., Corell, R., Kasperson, R., McCarthy, J. J., Cash, D., Cohen, S. J., Desanker, P., Dickson, N. M. Epstein, P., Guston, D. H., Hall, J. M., Jaeger, C., Janetos, A., Leary, N., Levy, M.A., Luers, A., MacCracken, M., Melillo, J., Moss, R., Nigg, J. M., Parry, M. L., Parson, E. A., Ribot, J. C., Schellnhuber, H-J., Seielstad, G. A., Shea, E., Vogel, C., Wilbanks, T. J., 2000. *Assessing Vulnerability to Global Environmental Risks*. Belfer Center for Science & International Affairs.

Cooper, R. 2000. International approaches to global climate change. *World Bank Research Observer* 15(2), 145-172.

Corfee-Morlot, J. and Höhne, N. 2003. Climate change: long-term targets and short-term commitments, *Global Environmental Change* 13, 277-293.

Corbett, J. 1988. Famine and household coping strategies. *World Development* 16*,* 1099-1112.

Crichton, D., 1999. The risk triangle, in Ingleton, J. (ed.), *Natural Disaster Management*. Tudor Rose, London, pp 102-103.

Cross, J. A. 2001. Megacities and small towns: different perspectives on hazard Vulnerability. *Environmental Hazards* 3, 63–80.

Cullen, H. M., deMenocal, P. B., Hemming, S., Hemming, G., Brown, F. H., Guilderson, T. and Sirocko, F. 2000. Climate change and the collapse of the Akkadian empire: Evidence from the deep-sea. *Geology*, 28 (4), 379-382.

Cutter, S. 1996. Vulnerability to environmental hazards. *Progress in Human Geography* 20 (4), 529–539.

Cutter, S., J. Mitchell, and M. Scott. 2000. Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers* 90 (4),713 – 737.

Davies, S.(1993. Are coping strategies a cop out? *IDS Bulletin* 24*,* 60-72.

De Waal, A. (1989) *Famine that Kills: Darfur, Sudan, 1984-1985.* Clarendon Press, Oxford.

Denton, F. 2002. Climate change vulnerability, impacts, and adaptation: why does gender matter? *Gender and Development*, 10 (2), 10-20.

Dercon, S. 2001. *Income risk, coping strategies and safety nets*. Centre for the Study of African Economies Working Paper WPS2000.26. CSAE, Oxford.

Dercon, S. and Krishnan, P. 1996. Income portfolios in rural Ethiopia and Tanzania: choices and constraints. *Journal of Development Studies* 32, 850-875.

Devereux, S., and T. Naeraa. 1996. Drought and survival in rural Namibia. Journal of *Southern African Studies* 22, 421-440.

Dow, K. 1992. Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. *Geoforum* 23 (3), 417-436.

Downing, T. E. and Patwardhan, A. 2003. Vulnerability assessment for climate adaptation, *Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change*, UNDP.

Downing, T. E., Butterfield, R., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y. and Stephen, L. 2001. *Vulnerability Indices: Climate Change Impacts and Adaptation*. UNEP Policy Series, UNEP, Nairobi.

Downing, T.E., Watts, M.J., and Bohle, H.G. 1995. Climate Change and Food Insecurity: Towards a Sociology and Geography of Vulnerability. In: Downing, T.E. (Ed.) *Climate Change and World Food Security,* pp. 183-206. Srpinger, Berlin, Heidelberg, New York, Barcelona, Budapest, Hong Kong, London, Milan, Paris, Santa Clara, Singapore and Tokyo.

Downing, T.E. 1992. *Climate change and vulnerable places: Global food security and country studies in Zimbabwe, Kenya, Senegal and Chile*. Environmental Change Unit Research Report. Oxford: University of Oxford

Drèze, J., and A. Sen. 1989. *Hunger and public action.* Oxford: Clarendon Press.
Ellis, F. 1998. Household strategies and rural livelihood diversification. *The Journal of Development Studies* 35,1-38.

Eriksen, Siri, 2003. The role of indigenous plants in household adaptation to climate change: The Kenyan experience. In: Low, P. S. (ed.), *Climate Change for Africa: Science, Technology, Policy and Capacity Building*. Kluwer Academic Publishers. 371-392 pp. (In Press).

Fearnside, P. M., 2003. Conservation policy in Brazilian Amazonia: Understanding the dilemmas. *World Development* 31 (5), 757-779.

Fermann, G. 1997. Political Context of Climate Change, in Fermann, G., ed. *International Politics of Climate Change: Key Issues and Critical Actors.* Scandinavian University Press, Oslo, pp. 11- 52.

FEWSNET, 2000. *Annual Performance and Monitoring Report for the Year 2000*. Famine Early Warming System Network (FEWS NET), Chemonics International Inc., Washington DC. www.fews.net/resources/gcontent/pdf/1000053.pdf accessed 17.02.2003.

Fine, B., 1999. The developmental state is dead – long live social capital? *Development and Change* 30, 1-19.

FIVIMS. 2000. Report on the Geneva meeting on Vulnerability: Fifth meeting of the subgroup on indicators, assessment and mapping, Geneva from 10 - 11 July 2000. Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS), Rome. http://www.fivims.net. Accessed 17. February 2003.

Frich, P, Alexander, LV, Della-Marta, P, Gleason, B, Haylock, M, Klein Tank, AMG and Peterson, T (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research* 19, 193-212.

GECHS, 2000. The Index of Human Insecurity, *AVISO* Issue No. 6.

Glantz, M.H. 1994. Drought, Desertification and Food Production. In: Glantz, M.H. (Ed.) *Drought Follows the Plough*, pp 7-30. Cambridge: Cambridge University Press.

Gore, C. 1993. Entitlement relations and 'unruly' social practices: a comment on the work of Amartya Sen. *The Journal of Development Studies* 29, 429-460.

Grant, W., 2000. *Globalisation, big business and the Blair government*. Centre for the Study of Regionalization and Globalisation Working Paper No. 58/00, University of Warwick, UK.

Guyer, J.I. 1997. Endowments and Assets: The Anthropology of Wealth and the Economics of Intrahousehold Allocation. In: Haddad, L., Hoddinott, J., and Alderman, H. (Eds.) *Intrahousehold Resource Allocation in Developing Countries: Models, Methods and Policy,* pp. 112-125. Baltimore: The Johns Hopkins University Press.

Haddad, L., E. Kennedy, et al. 1994. Choice of indicators for food security and nutrition monitoring. *Food Policy* 19(3), 329-343

Hamilton, C., 1999. The genuine progress indicator methodological developments and results from Australia, *Ecological Economics* 30, 13-28.

Hareau, A., Hofstadter, R. and Saizar, A., 1999. Vulnerability to climate change in Uraguay: potential impacts on the agricultural and coastal resource sectors and response capabilities. *Climate Research* 12, 185-193.

Helm, P., 1996. Integrated risk management for natural and technological disasters. *Tephra* 15 (1), 4-13.

Homewood, K. 1995. Pastoralist production systems and climate change. In T. E. Downing (Ed.) *Climate change and world food security*, pp. 505-524. Berlin, Heidelberg, New York, Barcelona, Budapest, Hong Kong, London, Milan, Paris, Santa Clara, Singapore and Tokyo: Springer.

Huq, S. 2002. Adaptation and sustainable development. *Tiempo*, Issue 46, December 2002, 23-25.

Hulme, M. 1996. Recent climatic change in the world's drylands, *Geophysical Research Letters* 23, 61-64.

IPCC, 2001. Climate change 2001: Impacts, Adaptation and Vulnerability, Summary for Policymakers, WMO.

Jallow, B.P., Barrow, M.K.A. and Leatherman, S.P. 1996. Vulnerability of the coastal zone of The Gambia to sea level rise and development of response strategies and adaptation options. *Climate Research* 6, 165-177.

Jodha, N.S. 1990. Rural common property resources: contributions and crisis. *Economic and Political Weekly* 25, A-65-A-78.

Jodha, N.S. 1995. Enhancing Food Security in A Warmer and More Crowded World: Factors and Processes in Fragile Zones. In: Downing, T.E. (Ed.) *Climate Change and World Food Security,* pp. 381-419. Berlin, Heidelberg, New York, Barcelona, Budapest, Hong Kong, London, Milan, Paris, Santa Clara, Singapore and Tokyo: Springer.

Jones, R. and Boer, R., 2003. Assessing current climate risks *Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change*, UNDP, in review, see http://www.undp.org/cc/apf-outline.htm).

Jones, R. and Mearns, L., 2003. Assessing future climate risks *Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change*, UNDP, in review, see http://www.undp.org/cc/apf-outline.htm).

Jordan, A., I. Lorenzoni, et al. (2000). Co-evolutionary Approach to Climate Change Impact Assessment: A Scenario-Based Study in the UK. Norwich, Centre for Social and Economic Research on the Global Environment.

Kabuta, S. H. and Laane, R. W. P. M., 2003. Ecological performance indicators in the North Sea: development and application, *Ocean and Coastal Management* 46, 277-297.

Kamau, C.M., Anyango, G.J., Gitahi, M., Wainaina, M. and Downing, T.E. (1989) Case Studies of Drought Impacts and Responses in Central and Eastern Kenya. In: Downing, T.E., Gitu, K.W. and Kamau, C.M. (Eds.) *Coping with Drought in Kenya: National and Local Strategies*, pp. 211-230. Boulder and London: Lynne Rienner Publishers.

Kandlikar, M. and J. Risbey. 2000. Agricultural impacts of climate change: If adaptation is the answer, what is the question? An Editorial Comment. *Climatic Change* 45, 529-539.

Kasperson, R.E., Kasperson, J.X. and Dow, K., 2001. 'Introduction: Global environmental risk and society' in Kasperson, J.X. and Kasperson, R. (eds.) *Global* *environmental risk*, United Nations University Press and Easrthscan, Tokyo, New York, Paris, London.

Kasperson, J. X., R. E. Kasperson, et al., 1996. Regions at Risk: Exploring Environmental Criticality. *Environment* 38(10): 4-15, 26-29.

Kasperson, R. 2001. Vulnerability and global environmental change. *IHDP Update* 2001 2, 2-3.

Kates, R.W. and Haarmann, V., 1992. Where the poor live: are the assumptions correct? *Environment* 34, 4-11,25-28.

Kelly, P. M., 2000. Towards a sustainable response to climate change. In: *Science and Environmental Decision Making,* ed. M. Huxham and D. Sumner, 118-141. Pearson Education, Harlow, 268pp.

Kelly, P.M. and W.N. Adger. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47 (4), 325-352.

Klepper, G. and K. Springer, 2003. Climate protection strategies: International allocation and distribution effects. Clmatic Change 56(1), 211-226.

Kasperson, R. E., Kasperson, J. X. and Dow, K., 2001. Vulnerability, equity, and global environmental change, in Kasperson, J. X. and Kasperson, R. E. (eds.), *Global Environmental Risk*, United Nations University Press and Earthscan, 247-272.

Kaufmann, D., Kraay, A. and Zoido-Lobatón, P., 1999a. *Governance Matters*. mimeo., World Bank, Washington DC.

Kaufmann, D., Kraay, A. and Zoido-Lobatón, P., 1999b. Aggregating governance indicators. Policy Research Working Paper 2195, World Bank, Washington DC.

Kelman, I., 2003. Defining risk, *Flood Risk Net Newsletter*, Issue 2, Winter 2003

Kosack, S., 2003. Effective aid: How democracy allows development aid to improve the quality of life. *World Development* 31 (1), 1-22.

Leichenko, R. M. and K. L. O'Brien, 2002. The Dynamics of Rural Vulnerability to Global Change: The Case of southern Africa. *Mitigation and Adaptation Strategies for Global Change* 7(1): 1-18.

Liverman, D.M. 1990 Vulnerability to global environmental change. In *Understanding Global Environmental Change*, eds. R.E.Kasperson *et al.,* pp. 8-23, Worcester, MA: The Earth Transformed Program.

Lochner, K., Kawachi, I. and Kennedy, B. P., 1999. Social capital: a guide to its measurement. *Health and Place* 5, 259-270.

Mbithi, P.M., and Wisner, B., 1973. Drought and famine in Kenya: magnitude and attempted solutions. *Journal of Eastern African Research and Development* 3*,* 113-143.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (eds). 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Mitchell, T. D. and M. Hulme, 1999. Predicting regional climate change: living with uncertainty. *Progress in Physical Geography* 23(1), 57-78.

Morrow, B. H. 1999. Identifying and mapping community vulnerability. *Disasters* 24 (1), 1-18.

Morgan, M. G. and Henrion, M., 1990, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*. Cambridge University Press, pp 332.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., and Kent, J., 2000. Biodiversity hotspots for conservation priorities. *Nature* 403*,* 853-858.

Netting, R.M., 1993. *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture*. Stanford: Stanford University Press.

Ndikumana, L. and Boyce, J. K., 2003. Public debts and private assets: Explaining capital flight from sub-Saharan African Countries. *World Development*, 31 (1), 107-130.

Neumayer, E., Gates, S. and Gleditsch, N. P., 2002. *Environmental Commitment, Democracy and Inequality, A Background Paper to World Development Report 2003*.

Nicholls, R. J. and Small, C., 2002. Improved estimates of coastal populations and exposure to hazards released. *EOS* 83 (28), pp 301 and 305.

Nicholls, R. J., Hoozemans, F. M. J. and Marchand, M., 1999. Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change* 9, S69-S87.

Nypan, A. 1991. Women's work and strategies for control of resources: Changes in the position of rural women in Tanzania. *FORUM for utviklingsstudier* (1): 79-97.

O'Brien, K. L. and Leichenko, R. M. 2000. Double Exposure: Assessing the Impacts of Climate Change Within the Context of Economic Globalization. *Global Environmental Change* 10, 221-232.

O'Riordan, T., Cooper, C. L., Jordan, A., Rayner, S., Richards, K. R., Runci, P. and Yoffe, S., 1998. Institutional frameworks for political action. In Rayner, S. and Malone, E. (eds.) *Human Choice and Climate Change: Volume 1 The Societal Framework*. Battelle Press: Washington DC pp. 345-439.

Paldam, M. and Svendsen, G. T., 2000. An essay on social capital: looking for the fire behind the smoke. *European Journal of Political Economy* 16, 339-366.

Parry, M. L. E. ed., 2000. *Assessment of the Potential Effects and Adaptations for Climate Change in Europe*. Norwich, Jackson Environment Institute, University of East Anglia, UK.

Parry, M., N. Arnell, et al. 2001. Millions at risk: defining critical climate change threats and targets. *Global Environmental Change-Human And Policy Dimensions,* 11(3), 181-183.

Parry, M., Rosenzweig, C., Iglesias, A., Fischer, G. and Livermore, M. 1999. Climate change and world food security: a new assessment. *Global Environmental Change*, 9, S51-S67.

Peduzzi, P., 2000. *Insight on common/key indicators for Global Vulnerability Mapping*. Presentation at Expert Meeting on Vulnerability and Risk Analysis and Indexing, Geneva, 11-12 September 2000. Available at: http://www.grid.unep.ch/activities/earlywarning/preview/appl/reports/vul_risk.pdf.

Pelling, M. and Uitto, J. I., 2001. Small island developing states: natural disaster vulnerability and global change. *Environmental Hazards* 3, 49–62.

Platteau, J. P. 1991. Traditional systems of social security and hunger insurance: Past achievements and modern challenges. In E. Ahmad, J. Dreze, J. Hills and A. Sen, (Eds.) *Social secutiry in developing countries,* pp. 112-170. Oxford: Clarendon Press.

Polsky, C. and I. Easterling, William E. 2001. Adaptation to climate variability and change in the US Great Plains: A multi-scale analysis of Ricardian climate sensitivities, Agriculture. *Ecosystems & Environment* 85(1-3), 133-144.

Pottier, J. 1988. *Migrants No More: Settlement and Survival in Mambwe Villages, Zambia*, Manchester: Manchester University Press.

Ramachandran, M. and Eastman, R. J. 1997. Applications of GIS to Vulnerability Mapping: A West African Food Security Case Study, The Idrisi Project, Clark Labs for Cartographic Technology and Geographic Analysis, Clark University. www.clarklabs.org/10applic/risk/Chapter3/Chapter3.htm

Random House, 1966. *The Random House Dictionary of the English Language*, Stein, J. (ed.), Random House, New York.

Reardon, T. and Matlon, P. 1989 Seasonal Food Insecurity and Vulnerability in Drought-Affected Regions of Burkina Faso. In: Sahn, D.E. (Ed.) *Seasonal Variability in Third World Agriculture: The Consequences for Food Security*, pp. 118-136. Baltimore: International Food Policy Research Institute/Johns Hopkins University Press.

Rice, J., 2003. Environmental health indicators. *Ocean and Coastal Management* 46, 235-259.

Roberts, N., 1998. *The Holocene: An Environmental History*. Oxford, Blackwell

Sarewitz, D., Pielke, R. and Keykhah, M. 2003. Vulnerability and risk: some thoughts from a political and policy perspective. *Risk Analysis* 23, 805-810.

Schiller, A., de Sherbinin, A., Hsieh, W-H. and Pulsipher, A. 2001. The Vulnerability of Global Cities to Climate Hazards. IHDP Open Meeting 2001, Rio de Janeiro. Sedac.ciesin.org/openmeeting/downloads/1008002293_presentation_aschiller_riopaper1220.pdf

Schneider, S. and Sarukhan, J. 2001. Overview of impacts, adaptation, and vulnerability to climate change, in *Climate Change 2002.* In McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (eds.) *Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, Cambridge.

Sear, C., Hulme, M., Adger, N. and Brown, K. 2001. *The Impacts of Global Climate Change on the UK Overseas Territories: Issues and Recommendations - A Summary Report*. Natural Resources Institute and Tyndall Centre for Climate Change Research

Sen, A.K. 1981. *Poverty and Famines: An Essay on Entitlement and Deprivation*. Clarendon, Oxford.

Smit, B. and Pilifosova, O. 2001. Adaptation to climate change in the context of sustainable development and equity, *Climate Change 2001:Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Third Assessment report of the Intergovernmental Panel on Climate Change. WMO/UNEP, 877-912.

Smit, B., Burton, I., Klein, R. J. T. and Wandel, J. 2000. An anatomy of adaptation to climate change and variability. *Climatic Change* 45, 223-451.

Smit, B., Burton, I., Klein, R. J. T. and Street, R. 1999. The science of adaptation: a framework for assessment. *Mitigation and Adaptation Strategies for Global Change* 4, 199-213.

Smith, K., 1996. *Environmental Hazards*. Routeledge, London, pp 389.

Smith, B., I. Burton, R.J.T. Klein, and J. Wandel. 2000. An anatomy of adaptation to climate change and variability. *Climatic Change* 45 (1), 223-251.

Smith, N. and O'Keefe, P., 1996. Geography, Marx and the Concept of Nature. In: Agnew, J., Livingstone, D.N. and Rogers, A. (Eds.) *Human Geography: An Essential Anthology,* pp. 282-315. Blackwell Publishers: Oxford and Cambridge (USA).

Sousounis, P.J. and Bisanz, J.M. (eds). 2000. Preparing for a changing climate: The Potential Consequences of Climate Variability and Change. Great Lakes, a Summary by the Great Lakes Regional Assessment Group. University of Michigan, U.S. Global Change Research Programme.
www.gcrio.org/NationalAssessment/greatlakes/greatlakes.pdf

Steinberg, T., 2001. The secret history of natural disaster. *Environmental Hazards* 3, 31-35.

Stenchion, P. 1997. Development and disaster management, *Australian Journal of Emergency Management*, 12 (3), 40-44.

Stephen, L. and T.E. Downing. 2001. Getting the scale right: A comparison of analytical methods for vulnerability assessment of household-level targeting. *Disasters* 25 (2),113-135.

Stigter, K.J. 1995. Transfer of Indigenous Knowledge and Protection of the Agricultural Environment in Eastern Africa. In: Warren, D.M., Slikkerveer, L.J. and Brokensha, D. (Eds.) *The Cultural Dimension of Development: Indigenous Knowledge Systems*, pp. 419-425. London: Intermediate Technology Publications.

Sullivan, C. 2002. Calculating a water poverty index, *World Development* 30 (7), 1195-1210.

Swift, J. 1993. Understanding and preventing famine and famine mortality. *IDS Bulletin* 24 (4), 1-16.

Taylor, P.J. and Flint, C. 2000. Political Geography. World-economy, nation-state and locality. 4th edition. Pearson Education Limited, Harlow, UK.

Turner, B. L., 1991. Thought on Linking the Physical and Human Sciences in the Study of Global Environmental Change. *Research and Exploration* 7, 133-135.

Twigg, J. 2001. *Sustainable Livelihoods and Vulnerability to Disasters*, Disaster Management Working Paper 2/2001, Benfield Greig Hazard Research Centre.

United Nations, 2001. *Cities in a Globalising World: Global Report on Human Settlements 2001.* United Nations Centre for Human Settlements (HABITAT), Earthscan, London.

United Nations, 2002. Risk awareness and assessment. In *Living with Risk*, ISDR, UN, WMO and Asian Disaster Reduction Centre, Geneva, 39-78.

UNDHA, 1992. *Internationally Agreed Glossary of Basic Terms Related to Disaster Management*. United Nations Department of Humanitarian Affairs, Geneva.

U.S. Country Studies Program, 1999. Climate Change: Mitigation, Vulnerability and Adaptation in Developing Countries and Transition Countries. U.S. Country Studies Programme - support for Climate Change Studies, Plans and Technology Assessments, Washington D.C. www. gcrio.org/CSP/pdf/USCSPpdf_pg.html

UNDP (United Nations Development Programme). 1996. *Human Development Report.* Oxford University Press, Oxford.

USAID/FEWS Project, 1995. *Vulnerability assessment. Report on Kenya*, Arlington, Virginia: FEWS Project.

Vestal, T.M. 1991. Risk factors and predictability of famine in Ethiopia. *Politics and the Life Sciences* 9, 187-203.

Watts, M. 1983. *Silent Violence: Food, Famine and Peasantry in Northern Nigeria*, Berkeley: University of California Press.

Wilkie, D., Morelli, G., Rotberg, F. and Shaw, E. 1999. Wetter isn't better: global warming and food security in the Congo Basin. *Global Environmental Change* 9: 323-328.

Wisner, B. 2000. The political economy of hazards: more limits to growth? *Environmental Hazards* 20, 59-61.

World Bank. 1997. World development indicators, 1997. Washington D.C.: The World Bank.

World Economic Forum, 2002a. Environmental Sustainability Index, An Initiative of the Global Leaders of Tomorrow Task Force, World Economic Forum Annual Meeting 2002, WEF, Yale Center for Environmental Law and Policy (Yale University) and Center for International Earth Science Information Network (Columbia University).

World Economic Forum, 2002b. Pilot Environmental Performance Index, An Initiative of the Global Leaders of Tomorrow Task Force, World Economic Forum Annual Meeting 2002, WEF, Yale Center for Environmental Law and Policy (Yale University) and Center for International Earth Science Information Network (Columbia University).

Zambia National Vulnerability Assessment Committee, 2003. Zambia Emergency Food Security Assessment Report (January 2003) Zambia National Vulnerability Assessment Committee in collaboration with SADC FANR Vulnerability Assessment Committee, Lusaka. www.fews.net/resources/gcontent/pdf/1000224.pdf accessed 17.02.2003.

| ISO3 code | sanit | lit 15-24 | mat mort | lit 15+ | calories | voice-acc | civ libs | pol rights | gov effect | lit ratio | life exp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AFG | 5 | X | X | X | 5 | 5 | 5 | 5 | X | X | X |
| AGO | 4 | X | X | X | 5 | 5 | 5 | 5 | 5 | X | 5 |
| AIA | 1 | X | X | X | X | X | X | X | X | X | X |
| ALB | X | 1 | X | 1 | 2 | 3 | 3 | 3 | 4 | 3 | 1 |
| AND | 1 | X | X | X | X | X | X | X | X | X | X |
| ANT | X | X | X | X | 3 | X | X | X | X | X | X |
| ARE | X | X | X | X | 1 | 4 | X | X | 3 | X | X |
| ARG | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 2 | 3 | 2 | 1 |
| ARM | X | 1 | 1 | 1 | 4 | 3 | 3 | 3 | 4 | 2 | 1 |
| ATG | 1 | X | 1 | X | 3 | X | 3 | 3 | X | X | X |
| AUS | 1 | X | X | X | 1 | 1 | 1 | 1 | 1 | X | 1 |
| AUT | 1 | X | X | X | 1 | 1 | 1 | 1 | 2 | X | 1 |
| AZE | X | X | 1 | X | 4 | 4 | 4 | 4 | 4 | X | 2 |
| BDI | X | 3 | X | 4 | 5 | 5 | 5 | 4 | X | 4 | 5 |
| BEL | X | X | X | X | 1 | 1 | 1 | 1 | 2 | X | 1 |
| BEN | 5 | 4 | 3 | 4 | 3 | 2 | 3 | 2 | 3 | 5 | 4 |
| BFA | X | 5 | 3 | 5 | 4 | 3 | 3 | 4 | 3 | 5 | 5 |
| BGD | 3 | 4 | 2 | 4 | 4 | 3 | 3 | 2 | 4 | 4 | 3 |
| BGR | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 4 | 2 | 2 |
| BHR | X | 1 | 1 | 1 | X | 4 | 4 | 4 | 3 | 3 | 1 |
| BHS | 1 | 1 | X | 1 | 3 | 1 | 2 | 1 | 3 | 2 | 2 |
| BIH | X | X | X | X | 4 | 3 | 4 | 4 | 5 | 2 | 2 |
| BLR | X | 1 | 1 | 1 | 2 | 4 | 3 | 3 | 4 | 2 | 1 |
| BLZ | 4 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | X | 3 | 3 |
| BOL | 2 | 1 | 2 | 1 | 4 | 2 | 3 | 2 | 3 | 2 | 2 |
| BRA | 2 | 1 | 1 | 1 | 2 | 2 | 3 | 2 | 3 | X | 1 |
| BRB | 1 | X | X | X | 2 | 1 | 1 | 1 | X | X | X |
| BRN | X | X | X | X | 2 | 4 | 5 | 5 | 3 | X | X |
| BTN | 2 | X | 2 | X | X | 5 | X | X | X | X | 3 |
| BWA | X | 1 | 2 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 5 |
| CAF | 4 | 3 | 5 | 4 | 5 | 4 | 3 | 3 | 4 | 4 | 5 |
| CAN | 1 | X | X | X | 2 | 1 | 1 | 1 | 1 | X | 1 |
| CHE | 1 | X | 1 | X | 1 | 1 | 1 | 1 | 1 | X | 1 |
| CHL | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 1 |
| CHN | 4 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 3 | 3 | 2 |
| CIV | X | 3 | 3 | 4 | X | 4 | 4 | 4 | 3 | 4 | 4 |
| CMR | 1 | 1 | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 3 | 4 |
| COD | 5 | X | X | X | 5 | X | X | X | X | X | X |
| COG | X | 1 | X | 2 | 4 | 5 | 3 | 3 | 4 | 3 | 4 |
| COK | 1 | X | X | X | 3 | X | X | X | X | X | X |
| COL | 1 | 1 | 1 | 1 | X | 3 | 3 | 3 | 3 | 2 | 2 |
| COM | 1 | 3 | X | 3 | 5 | 3 | 3 | 3 | X | 3 | 3 |
| CPV | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | X | 3 | 2 |
| CRI | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 2 | 2 | 1 |
| CUB | 1 | 1 | 1 | 1 | 3 | 5 | 5 | 5 | 4 | 2 | 1 |
| CYP | 1 | 1 | X | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |
| CZE | X | X | 1 | X | 2 | 1 | 2 | 1 | 2 | X | 1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEU | X | X | 1 | X | 1 | 1 | 2 | 1 | 1 | X | 1 |
| DJI | 1 | 2 | X | 3 | 5 | 3 | 4 | 4 | X | 4 | 5 |
| DMA | X | X | 1 | X | 2 | 1 | 1 | 2 | X | X | X |
| DNK | X | X | 1 | X | 1 | X | 1 | 1 | 1 | X | 1 |
| DOM | 2 | 1 | 2 | 1 | 4 | 2 | 3 | 3 | 4 | 2 | 2 |
| DZA | 2 | 1 | 1 | 2 | 2 | 4 | 5 | 5 | 4 | 3 | 2 |
| ECU | 3 | 1 | 1 | 1 | 3 | 3 | 3 | 2 | 4 | 2 | 2 |
| EGY | 1 | 2 | 1 | 3 | 1 | 4 | 4 | 4 | 3 | 4 | 2 |
| ERI | 5 | 2 | 5 | 3 | 5 | 4 | 4 | 4 | X | 4 | 4 |
| ESP | X | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 |
| EST | X | X | X | X | 3 | 2 | X | X | 3 | X | X |
| ETH | 5 | 3 | X | 4 | 5 | 4 | 4 | 4 | 3 | 4 | 5 |
| FIN | 1 | X | 1 | X | 2 | 1 | 1 | 1 | 1 | X | 1 |
| FJI | 4 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 2 | 2 | 2 |
| FRA | X | X | 1 | X | 1 | 1 | 2 | 1 | 2 | X | 1 |
| FSM | X | X | X | X | X | X | 1 | 1 | X | X | X |
| GAB | 5 | X | 3 | X | 3 | 3 | 3 | 4 | 5 | X | 4 |
| GBR | 1 | X | 1 | X | 1 | 1 | 2 | 1 | 1 | X | 1 |
| GEO | X | X | 1 | X | 4 | 3 | 4 | 4 | 4 | X | 1 |
| GHA | 3 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 3 | 3 | 3 |
| GIN | 3 | X | 3 | X | 4 | 4 | 4 | 4 | 3 | X | 4 |
| GLP | 3 | X | X | X | X | X | X | X | X | X | X |
| GMB | 4 | 3 | X | 4 | 4 | 4 | 4 | 5 | 3 | 4 | 5 |
| GNB | 3 | 3 | 5 | 4 | 3 | 4 | 3 | 3 | 4 | 5 | 5 |
| GNQ | 3 | X | X | X | X | 5 | X | X | X | X | X |
| GRC | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 1 |
| GRD | X | X | 1 | X | 3 | X | 2 | 1 | X | X | X |
| GTM | 1 | 2 | 1 | 2 | 4 | 3 | 4 | 3 | 3 | 3 | 2 |
| GUF | 2 | X | X | X | X | X | X | X | X | X | X |
| GUY | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 3 | 2 | 2 |
| HKG | 1 | 1 | X | 1 | X | 3 | X | X | 2 | 2 | 1 |
| HND | 2 | 2 | 1 | 2 | 4 | 3 | 3 | 3 | 4 | 2 | 2 |
| HRV | X | 1 | 1 | 1 | 3 | 2 | 3 | 3 | 3 | 2 | 1 |
| HTI | 4 | 3 | 3 | 3 | 5 | 4 | 4 | 4 | 5 | 2 | 4 |
| HUN | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 2 |
| IDN | 2 | 1 | 2 | 1 | 2 | 3 | 4 | 5 | 4 | 3 | 2 |
| IND | 4 | 2 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 4 | 3 |
| IRL | X | X | 1 | X | 1 | 1 | 2 | 1 | 1 | X | 1 |
| IRN | 2 | 1 | 1 | 2 | 2 | 3 | 5 | 4 | 4 | 3 | 2 |
| IRQ | 2 | X | X | X | 4 | 5 | 5 | 5 | 5 | X | X |
| ISL | X | X | X | X | 2 | 1 | 1 | 1 | 1 | X | 1 |
| ISR | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 2 | 1 |
| ITA | X | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 1 |
| JAM | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 2 | 4 | 2 | 1 |
| JOR | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 2 | 3 | 2 |
| JPN | X | X | 1 | X | 2 | 1 | 2 | 2 | 2 | X | 1 |
| KAZ | 1 | X | 1 | X | 2 | 4 | 4 | 4 | 4 | X | 2 |
| KEN | 1 | X | X | X | 5 | 4 | 4 | 4 | 4 | X | X |
| KGZ | 1 | X | 1 | X | 4 | 4 | 3 | 3 | 4 | X | 2 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KHM | 5 | 2 | 2 | 2 | 4 | 4 | 4 | 3 | X | 4 | 3 |
| KIR | 3 | X | X | X | 3 | X | 1 | 1 | X | X | X |
| KNA | 1 | X | 1 | X | X | X | 2 | 2 | X | X | X |
| KOR | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 2 | 1 |
| KWT | X | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 3 | 2 | 1 |
| LAO | 3 | 2 | 3 | 4 | 4 | 4 | 4 | 5 | X | 5 | 4 |
| LBN | 1 | 1 | 1 | 1 | 1 | 3 | 4 | 4 | 3 | 3 | 1 |
| LBR | X | X | X | X | 4 | 4 | 4 | 5 | 4 | X | X |
| LBY | 1 | 1 | 1 | 2 | 1 | 5 | 5 | 5 | 5 | 3 | 2 |
| LCA | X | X | 1 | X | 3 | X | 2 | 1 | X | X | 1 |
| LKA | 1 | 1 | 1 | 1 | 4 | 3 | 4 | 3 | 4 | 2 | 2 |
| LSO | 1 | 1 | X | 1 | 4 | 3 | 3 | 3 | 4 | 1 | 4 |
| LTU | X | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 3 | 2 | 2 |
| LUX | X | X | X | X | X | 1 | 1 | 1 | 1 | X | 1 |
| LVA | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 3 | 3 | 2 | 2 |
| MAC | X | X | X | X | 3 | X | X | X | X | X | X |
| MAR | 2 | 3 | 2 | 4 | 2 | 3 | 4 | 4 | 3 | 4 | 2 |
| MCO | 1 | X | X | X | X | X | X | X | X | X | X |
| MDA | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 2 | 2 |
| MDG | 4 | 2 | 3 | 2 | 4 | 2 | 4 | 4 | 3 | 3 | 4 |
| MDV | 3 | 1 | 2 | 1 | 3 | 4 | 4 | 4 | X | 2 | 2 |
| MEX | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 2 | 1 |
| MKD | X | X | 1 | X | 3 | 3 | 3 | 3 | 4 | X | 1 |
| MLI | 2 | 3 | 3 | 4 | 4 | 2 | 4 | 5 | 3 | 4 | 4 |
| MLT | 1 | X | X | X | 1 | 1 | X | X | 2 | X | X |
| MMR | 3 | 1 | 2 | 1 | 3 | 5 | X | X | 5 | 3 | 3 |
| MNG | 4 | 1 | 1 | 1 | 5 | 2 | 3 | 2 | 3 | X | 3 |
| MOZ | 4 | 3 | 5 | 4 | 5 | 3 | 4 | 3 | 4 | 5 | 5 |
| MRT | 4 | 4 | 3 | 4 | 3 | 4 | 5 | 5 | X | 4 | 4 |
| MSR | 1 | X | X | X | X | X | X | X | X | X | X |
| MUS | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 3 | 2 | 2 |
| MWI | 2 | 2 | 5 | 3 | 4 | 3 | 5 | 4 | 4 | 4 | 5 |
| MYS | X | 1 | 1 | 1 | 2 | 3 | 4 | 3 | 2 | 3 | 1 |
| NAM | 4 | 1 | 2 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 5 |
| NCL | X | X | X | X | 2 | X | X | X | X | X | X |
| NER | 5 | 5 | 3 | 5 | 4 | 3 | 4 | 3 | 5 | 5 | 5 |
| NGA | 3 | 1 | X | 3 | 3 | 3 | 4 | 5 | 5 | 3 | 4 |
| NIC | 1 | 2 | 1 | 2 | 4 | 3 | 4 | 3 | 4 | 2 | 2 |
| NIU | 1 | X | X | X | X | X | X | X | X | X | X |
| NLD | 1 | X | 1 | X | 1 | 1 | 1 | 1 | 1 | X | 1 |
| NOR | X | X | 1 | X | 1 | 1 | 1 | 1 | 1 | X | 1 |
| NPL | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | X | 5 | 3 |
| NZL | X | X | 1 | X | 1 | 1 | 1 | 1 | 1 | X | 1 |
| OMN | 1 | 1 | 1 | 2 | X | 4 | 4 | 4 | 2 | 3 | 2 |
| PAK | 3 | 3 | X | 4 | 3 | 5 | 4 | 3 | 4 | 5 | 3 |
| PAN | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 2 | 3 | 2 | 1 |
| PER | 2 | 1 | 2 | 1 | 4 | 3 | 3 | 4 | 3 | 3 | 2 |
| PHL | 1 | 1 | 1 | 1 | 4 | 2 | 3 | 3 | 3 | 2 | 2 |
| PLW | 1 | X | X | X | X | X | X | X | X | X | X |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PNG | 1 | 2 | 2 | 3 | 4 | 3 | 3 | 2 | 4 | 3 | 3 |
| POL | X | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 |
| PRI | X | X | X | X | X | X | X | X | 2 | X | X |
| PRK | 1 | X | X | 1 | 4 | 5 | 5 | 5 | 4 | X | X |
| PRT | X | 1 | 1 | X | 1 | 1 | 1 | 1 | 2 | 2 | 1 |
| PRY | 1 | 1 | 1 | 1 | 3 | 4 | 3 | 3 | 5 | 2 | 2 |
| QAT | X | X | X | X | X | 4 | X | X | 3 | X | X |
| PYF | 1 | X | X | X | 2 | X | X | X | X | X | X |
| ROM | 3 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 2 | 2 |
| RUS | X | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 2 | 2 |
| RWA | 5 | 2 | X | 2 | 4 | 5 | 5 | 5 | X | 3 | 5 |
| SAU | 1 | 1 | X | 2 | 2 | 4 | 5 | 5 | 4 | 3 | 2 |
| SDN | 3 | 2 | 3 | 3 | 4 | 5 | 5 | 5 | 5 | 4 | 3 |
| SEN | 2 | 4 | 3 | 4 | 4 | 3 | 4 | 3 | 3 | 4 | 4 |
| SGP | 1 | X | X | X | X | 3 | X | X | 1 | X | X |
| SLB | 4 | X | 3 | X | 4 | 3 | 2 | 1 | X | X | 2 |
| SLE | 4 | X | X | X | 4 | 5 | 4 | 5 | 3 | X | 5 |
| SLV | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| SOM | X | X | X | X | 5 | 5 | 5 | 5 | 5 | X | X |
| STP | X | X | X | X | 4 | 2 | 2 | 1 | X | X | X |
| SUR | 1 | X | 1 | X | 3 | 2 | 3 | 3 | 3 | X | 2 |
| SVK | 1 | X | 1 | X | 2 | 2 | 3 | 2 | 3 | X | 1 |
| SVN | X | X | X | X | 2 | 1 | X | X | 2 | X | X |
| SWE | 1 | X | 1 | X | 2 | 1 | 1 | 1 | 1 | X | 1 |
| SWZ | X | 1 | 2 | 2 | 3 | 4 | 4 | 4 | 4 | 2 | 4 |
| SYC | X | X | X | X | 3 | X | 3 | 3 | X | X | X |
| SYR | 1 | 1 | 1 | 2 | 1 | 5 | 5 | 5 | 5 | 4 | 2 |
| TCA | 1 | X | X | X | X | X | X | X | X | 4 | 5 |
| TCD | 4 | X | X | X | 5 | 4 | 4 | 4 | 4 | X | X |
| TCH | X | 3 | 4 | 4 | X | X | X | X | X | X | X |
| TGO | 4 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| THA | 1 | 1 | 1 | 1 | 4 | 2 | 4 | 3 | 3 | 2 | 2 |
| TJK | X | 1 | 1 | 1 | 4 | 4 | 5 | 5 | 5 | 2 | 2 |
| TKM | X | X | 1 | X | 3 | 5 | 5 | 5 | 5 | X | 2 |
| TON | X | X | X | X | X | X | 3 | 4 | X | X | X |
| TTO | X | 1 | 1 | 1 | 3 | 2 | 2 | 1 | 2 | 2 | 1 |
| TUN | X | 1 | 1 | 2 | 1 | 4 | 4 | 4 | 2 | 3 | 2 |
| TUR | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 4 | 3 | 2 |
| TUV | 1 | X | X | X | X | X | 1 | 1 | X | X | X |
| TWN | X | X | X | X | X | 2 | X | X | 1 | X | X |
| TZA | 1 | 1 | 3 | 2 | 4 | 3 | 4 | 4 | 4 | 3 | 4 |
| UGA | 2 | 2 | 3 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 5 |
| UKR | X | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 2 | 2 |
| URY | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 2 | 2 | 1 |
| USA | 1 | X | 1 | X | 1 | 1 | 1 | 1 | 1 | X | 1 |
| UZB | 1 | 1 | 1 | 1 | 3 | 4 | 5 | 5 | 5 | 3 | 2 |
| VCT | 1 | X | 1 | X | 3 | X | 1 | 2 | X | X | X |
| VEN | 2 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 4 | 2 | 1 |
| VGB | 1 | X | X | X | X | X | X | X | X | X | X |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VNM | 2 | 1 | 1 | 1 | 4 | 5 | 5 | 5 | 4 | 2 | 2 |
| VUT | 1 | X | X | X | 3 | X | 3 | 1 | X | X | 2 |
| WLF | 2 | X | X | X | X | X | X | X | X | X | X |
| WSM | 1 | 1 | X | 2 | X | X | 2 | 2 | X | 2 | 2 |
| WTB | X | X | X | X | X | 3 | X | X | 3 | 2 | 4 |
| YEM | 3 | 3 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 3 |
| YUG | X | X | X | X | 2 | 3 | 4 | 4 | 4 | X | X |
| ZAF | 1 | 1 | X | 1 | 2 | 1 | 3 | 2 | 3 | 2 | 3 |
| ZAR | X | 2 | X | 3 | X | 5 | 4 | 5 | 5 | 4 | 4 |
| ZMB | 2 | 1 | 3 | 2 | 5 | 3 | 3 | 3 | 4 | 3 | 5 |
| ZWE | 2 | 1 | 4 | 1 | 4 | 4 | 4 | 4 | 5 | 3 | 5 |

**Appendix 2: Average vulnerability scores (x10), calculated as the mean of the individual scores (from 1 to 5) for the 11 variables exhibiting the strongest relationship with decadally aggregated mortality. N represents the number of variables (out of 11) for which data were available.**

| CODE | SCORE | N | CODE | SCORE | N | CODE | SCORE | N |
|---|---|---|---|---|---|---|---|---|
| AFG | 50 | 5 | BIH | 34 | 7 | SLB | 27 | 7 |
| COD | 50 | 2 | DJI | 34 | 9 | ARE | 27 | 3 |
| SOM | 50 | 5 | MLI | 34 | 11 | BWA | 26 | 10 |
| AGO | 48 | 7 | NGA | 34 | 10 | CUB | 26 | 11 |
| BDI | 43 | 8 | SEN | 34 | 11 | EGY | 26 | 11 |
| IRQ | 43 | 6 | YUG | 34 | 5 | EST | 26 | 3 |
| LBR | 42 | 5 | KHM | 33 | 10 | GHA | 26 | 11 |
| NER | 42 | 11 | TCA | 33 | 3 | IDN | 26 | 11 |
| SLE | 42 | 7 | ZWE | 33 | 11 | IRN | 26 | 11 |
| ETH | 41 | 10 | AZE | 32 | 7 | MDV | 26 | 10 |
| TCD | 41 | 6 | BGD | 32 | 11 | GTM | 26 | 11 |
| BFA | 40 | 10 | COG | 32 | 9 | HND | 25 | 11 |
| CAF | 40 | 11 | UGA | 32 | 11 | LSO | 25 | 10 |
| ERI | 40 | 10 | MDG | 31 | 11 | MKD | 25 | 7 |
| GMB | 40 | 10 | ANT | 30 | 1 | MNG | 25 | 10 |
| GNQ | 40 | 2 | BTN | 30 | 4 | NIC | 25 | 11 |
| MOZ | 40 | 11 | CMR | 30 | 11 | PER | 25 | 11 |
| MRT | 40 | 10 | COM | 30 | 9 | BHR | 25 | 9 |
| RWA | 40 | 9 | GEO | 30 | 7 | KWT | 24 | 10 |
| ZAR | 40 | 8 | GLP | 30 | 1 | OMN | 24 | 10 |
| BRN | 38 | 5 | IND | 30 | 11 | TUN | 24 | 10 |
| GNB | 38 | 11 | MAC | 30 | 1 | ALB | 24 | 9 |
| LAO | 38 | 10 | MAR | 30 | 11 | ARM | 23 | 10 |
| SDN | 38 | 11 | SWZ | 30 | 10 | DOM | 23 | 11 |
| GAB | 37 | 8 | SYC | 30 | 3 | LKA | 23 | 11 |
| HTI | 37 | 11 | TJK | 30 | 10 | PRY | 23 | 11 |
| MWI | 37 | 11 | TZA | 30 | 11 | TUR | 23 | 11 |
| PAK | 37 | 10 | ZMB | 30 | 11 | ATG | 23 | 5 |
| TKM | 37 | 7 | CHN | 29 | 11 | BLR | 22 | 10 |
| CIV | 36 | 9 | SAU | 29 | 10 | ECU | 22 | 11 |
| GIN | 36 | 8 | SYR | 29 | 11 | FJI | 22 | 11 |
| KEN | 36 | 6 | VNM | 29 | 11 | RUS | 22 | 10 |
| TCH | 36 | 3 | DZA | 28 | 11 | STP | 22 | 4 |
| TGO | 36 | 11 | LBY | 28 | 11 | SUR | 22 | 8 |
| YEM | 36 | 11 | MMR | 28 | 9 | UKR | 22 | 10 |
| NPL | 35 | 10 | UZB | 28 | 11 | BOL | 22 | 11 |
| PRK | 35 | 7 | KAZ | 27 | 8 | MYS | 21 | 10 |
| QAT | 35 | 2 | KGZ | 27 | 8 | ROM | 21 | 11 |
| TON | 35 | 2 | NAM | 27 | 11 | SLV | 21 | 11 |
| BEN | 34 | 11 | PNG | 27 | 11 | THA | 21 | 11 |

| **CODE** | **SCORE** | **N** | **CODE** | **SCORE** | **N** | | | |
|---|---|---|---|---|---|---|---|---|
| VEN | 21 | 11 | TWN | 15 | 2 | | | |
| COK | 21 | 2 | URY | 15 | 11 | | | |
| COL | 20 | 10 | CRI | 14 | 11 | | | |
| GUF | 20 | 1 | CZE | 14 | 7 | | | |
| HRV | 20 | 10 | DMA | 14 | 5 | | | |
| JOR | 20 | 11 | ISR | 14 | 11 | | | |
| KIR | 20 | 4 | POL | 14 | 10 | | | |
| LBN | 20 | 11 | GRC | 13 | 11 | | | |
| MDA | 20 | 11 | HUN | 13 | 11 | | | |
| MEX | 20 | 11 | ITA | 13 | 10 | | | |
| NCL | 20 | 1 | BRB | 12 | 5 | | | |
| PHL | 20 | 11 | CYP | 12 | 10 | | | |
| PRI | 20 | 1 | ESP | 12 | 10 | | | |
| VUT | 20 | 5 | FRA | 12 | 7 | | | |
| WLF | 20 | 1 | MLT | 12 | 4 | | | |
| BLZ | 20 | 10 | PRT | 12 | 9 | | | |
| JAM | 19 | 11 | AUT | 11 | 7 | | | |
| LVA | 19 | 11 | BEL | 11 | 6 | | | |
| ZAF | 19 | 10 | CAN | 11 | 7 | | | |
| BGR | 19 | 11 | DEU | 11 | 7 | | | |
| BRA | 18 | 10 | FIN | 11 | 8 | | | |
| CPV | 18 | 10 | GBR | 11 | 8 | | | |
| GUY | 18 | 11 | IRL | 11 | 7 | | | |
| KOR | 18 | 11 | ISL | 11 | 6 | | | |
| PAN | 18 | 11 | SWE | 11 | 8 | | | |
| SVK | 18 | 8 | AIA | 10 | 1 | | | |
| ARG | 18 | 11 | AND | 10 | 1 | | | |
| BHS | 17 | 10 | AUS | 10 | 7 | | | |
| GRD | 17 | 4 | CHE | 10 | 8 | | | |
| LTU | 17 | 10 | DNK | 10 | 6 | | | |
| WSM | 17 | 7 | FSM | 10 | 2 | | | |
| CHL | 17 | 11 | LUX | 10 | 5 | | | |
| LCA | 16 | 5 | MCO | 10 | 1 | | | |
| SGP | 16 | 3 | MSR | 10 | 1 | | | |
| SVN | 16 | 3 | NIU | 10 | 1 | | | |
| TTO | 16 | 10 | NLD | 10 | 8 | | | |
| VCT | 16 | 5 | NOR | 10 | 7 | | | |
| HKG | 16 | 7 | NZL | 10 | 7 | | | |
| JPN | 15 | 7 | PLW | 10 | 1 | | | |
| KNA | 15 | 4 | TUV | 10 | 3 | | | |
| MUS | 15 | 11 | USA | 10 | 8 | | | |
| PYF | 15 | 2 | VGB | 10 | 1 | | | |

| **CODE** | **SCORE** | **N** | **CODE** | **SCORE** | **N** | | | |
|---|---|---|---|---|---|---|---|---|
| VEN | 21 | 11 | TWN | 15 | 2 | | | |
| COK | 21 | 2 | URY | 15 | 11 | | | |
| COL | 20 | 10 | CRI | 14 | 11 | | | |
| GUF | 20 | 1 | CZE | 14 | 7 | | | |
| HRV | 20 | 10 | DMA | 14 | 5 | | | |
| JOR | 20 | 11 | ISR | 14 | 11 | | | |
| KIR | 20 | 4 | POL | 14 | 10 | | | |
| LBN | 20 | 11 | GRC | 13 | 11 | | | |
| MDA | 20 | 11 | HUN | 13 | 11 | | | |
| MEX | 20 | 11 | ITA | 13 | 10 | | | |
| NCL | 20 | 1 | BRB | 12 | 5 | | | |
| PHL | 20 | 11 | CYP | 12 | 10 | | | |
| PRI | 20 | 1 | ESP | 12 | 10 | | | |
| VUT | 20 | 5 | FRA | 12 | 7 | | | |
| WLF | 20 | 1 | MLT | 12 | 4 | | | |
| BLZ | 20 | 10 | PRT | 12 | 9 | | | |
| JAM | 19 | 11 | AUT | 11 | 7 | | | |
| LVA | 19 | 11 | BEL | 11 | 6 | | | |
| ZAF | 19 | 10 | CAN | 11 | 7 | | | |
| BGR | 19 | 11 | DEU | 11 | 7 | | | |
| BRA | 18 | 10 | FIN | 11 | 8 | | | |
| CPV | 18 | 10 | GBR | 11 | 8 | | | |
| GUY | 18 | 11 | IRL | 11 | 7 | | | |
| KOR | 18 | 11 | ISL | 11 | 6 | | | |
| PAN | 18 | 11 | SWE | 11 | 8 | | | |
| SVK | 18 | 8 | AIA | 10 | 1 | | | |
| ARG | 18 | 11 | AND | 10 | 1 | | | |
| BHS | 17 | 10 | AUS | 10 | 7 | | | |
| GRD | 17 | 4 | CHE | 10 | 8 | | | |
| LTU | 17 | 10 | DNK | 10 | 6 | | | |
| WSM | 17 | 7 | FSM | 10 | 2 | | | |
| CHL | 17 | 11 | LUX | 10 | 5 | | | |
| LCA | 16 | 5 | MCO | 10 | 1 | | | |
| SGP | 16 | 3 | MSR | 10 | 1 | | | |
| SVN | 16 | 3 | NIU | 10 | 1 | | | |
| TTO | 16 | 10 | NLD | 10 | 8 | | | |
| VCT | 16 | 5 | NOR | 10 | 7 | | | |
| HKG | 16 | 7 | NZL | 10 | 7 | | | |
| JPN | 15 | 7 | PLW | 10 | 1 | | | |
| KNA | 15 | 4 | TUV | 10 | 3 | | | |
| MUS | 15 | 11 | USA | 10 | 8 | | | |
| PYF | 15 | 2 | VGB | 10 | 1 | | | |

Tyndall°Centre
for Climate Change Research

The inter-disciplinary Tyndall Centre for Climate Change Research undertakes integrated research into the long-term consequences of climate change for society and into the development of sustainable responses that governments, business-leaders and decision-makers can evaluate and implement. Achieving these objectives brings together UK climate scientists, social scientists, engineers and economists in a unique collaborative research effort.

Research at the Tyndall Centre is organised into four research themes that collectively contribute to all aspects of the climate change issue: Integrating Frameworks; Decarbonising Modern Societies; Adapting to Climate Change; and Sustaining the Coastal Zone. All thematic fields address a clear problem posed to society by climate change, and will generate results to guide the strategic development of climate change mitigation and adaptation policies at local, national and global scales.

The Tyndall Centre is named after the 19th century UK scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge.

The Tyndall Centre is a partnership of the following institutions:

- University of East Anglia
- UMIST
- Southampton Oceanography Centre
- University of Southampton
- University of Cambridge
- Centre for Ecology and Hydrology
- SPRU – Science and Technology Policy Research (University of Sussex)
- Institute for Transport Studies (University of Leeds)
- Complex Systems Management Centre (Cranfield University)
- Energy Research Unit (CLRC Rutherford Appleton Laboratory)

The Centre is core funded by the following organisations:

- Natural Environmental Research Council (NERC)
- Economic and Social Research Council (ESRC)
- Engineering and Physical Sciences Research Council (EPSRC)
- UK Government Department of Trade and Industry (DTI)

For more information, visit the Tyndall Centre Web site (www.tyndall.ac.uk) or contact:

External Communications Manager
Tyndall Centre for Climate Change Research
University of East Anglia, Norwich NR4 7TJ, UK
Phone: +44 (0) 1603 59 3906; Fax: +44 (0) 1603 59 3901
Email: tyndall@uea.ac.uk

Tyndall°Centre
for Climate Change Research

## Recent Tyndall Centre Technical Reports

Tyndall Centre Technical Reports are available online at
http://www.tyndall.ac.uk/publications/tech_reports/tech_reports.shtml

Warren, R. (2002). **A blueprint for integrated assessment of climate change**, Tyndall Centre Technical Report 1.

Gough, C., Shackley, S., Cannell, M.G.R. (2002). **Evaluating the options for carbon sequestration**, Tyndall Centre Technical Report 2.

Köhler, J.H. (2002). **Modelling technological change**, Tyndall Centre Technical Report 3.

Goodess, C.M. Osborn, T. J. and Hulme, M. (2003) **The identification and evaluation of suitable scenario development methods for the estimation of future probabilities of extreme weather events,** Tyndall Centre Technical Report 4.

Steemers, K. (2003) **Establishing research directions in sustainable building design.** Tyndall Centre Technical Report 5.

Macmillan, S. and Köhler, J.H., (2004) **Modelling energy use in the global building stock: a pilot survey to identify available data,** Tyndall Centre Technical Report 6.

Adger W. N., Brooks, N., Kelly, M., Bentham, S. and Eriksen, S. (2004) **New indicators of vulnerability and adaptive capacity**, Tyndall Centre Technical Report 7.