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Abstract

We use data relating to natural disasters for the assessment of recent historical and current risk associated with climatic variability. Several proxies for risk and vulnerability are developed from the available data and discussed in terms of the meaning and implications of risk proxies. The numbers of people killed and otherwise affected by discrete climate-related natural disasters over the final decades of the twentieth century may be as a proxy for climatic risk. We recognise that natural disasters result from the interaction of hazard and vulnerability. In the case of climate related disasters, hazard represents the likelihood of occurrence, and potential severity of, events such as droughts, floods and storms, while vulnerability represents the set of social, economic, political and physical factors that determine the amount of damage a given event will cause. The countries at greatest risk from present climate-related disasters are nearly all developing countries with many of them showing a high degree of consistency in their rankings over the time periods (1971-80, 1981-1990, 1991-2000) examined. Current risk associated with extreme climate events is therefore a reasonable proxy for risk associated with climate change in the near future. Countries that are unable to cope with current climate hazards will be the most poorly equipped to cope with the adverse impacts of climate change; any increase in the frequency or severity of extreme climate events is likely to exacerbate their vulnerability.

Keywords: climate change, disasters, adaptation, risk, vulnerability, mortality

1. Introduction

Popular perception throughout the world, reflected for example through the media, is that the weather is changing and the world is becoming a riskier place over time. These perceptions are partly a result of greater information on global environmental change, and partly based on individuals' direct and indirect observation of extreme events in weather as part of their formulation of perceptions. In Germany, Poland, Netherlands, Czech Republic, UK, USA, Vietnam, India, Mozambique and many other countries, catastrophic floods have caused loss of life and damage to property and economies in the past decades. In many of these cases the floods are reported as having return periods of over a century, but their coincidence in various parts of the world enhances the perception that such events are indeed increasing. Cultural processes embody collective perceptions - many of these processes suggest crisis and change, particularly in the natural world (Crumley, 2000). This paper defines national level risk from climate-related disasters and examines the implications of recent historical trends in these phenomena.

There is evidence from various sources that suggests that climate-related events are increasing in frequency at the global scale, yet these are not necessarily caused by meteorological changes, and are not necessarily, or at least exclusively, attributable to global climate change (see IPCC, 2001). But we, as a global society, perceive greater danger (Dessai et al., 2002). Clearly the global climate has been changing over the past century and future projected changes will have great impact on societies. The need for adaptation may therefore be greatest in those areas, regions and sectors of

society that are already at the edge of their coping ranges (see Smit et al., 2001; Jones et al., 2002; Burton *et al.*, 2002).

In this paper we assess the potential of data relating to natural disasters for the assessment of recent historical and current risk associated with climatic variability (which may contain a component related to anthropogenic climate change) at the national level. We use numbers of people killed and otherwise affected by climate-related natural disasters over the final decades of the twentieth century as a proxy for climatic risk. It is worth emphasising again that risk is not the same as vulnerability. While the countries exhibiting the greatest numbers of people killed and affected are likely to be highly vulnerable to extreme climate-related events, there are also likely to be a number of countries that whose exposure to climate hazards is relatively low but who's inherent vulnerability to climate extremes is high – these countries are likely to suffer significant adverse impacts in the event of qualitative changes in the global climate. Other countries may have relatively low vulnerability but score highly as a result of the occurrence of unusual but particularly severe climate extremes, such as those apparent in the historical record but associated with long return periods. High levels of risk can result from either high vulnerability or high levels of hazard; the countries most at risk are those that experience both.

Natural disasters result from the interaction of hazard and vulnerability. In the case of climate related disasters, hazard represents the likelihood of occurrence, and potential severity of, events such as droughts, floods and storms, while vulnerability represents the set of social, economic, political and physical factors that determine the amount of damage a given event will cause. For human systems, vulnerability is therefore essentially socially constructed and determined (Bohle *et al*., 1994, Adger and Kelly, 1999). Vulnerability is both hazard- and system-specific; we can only talk meaningfully about the vulnerability *of* a particular population group or system *to* a particular hazard.

In current understanding of natural hazards, it is the interaction of hazard with vulnerability that constitutes risk (Burton et al., 1993; Downing et al., 2001). Indeed, if we are concerned with the likelihood that a system, country or population will be adversely affected by climate change, we are in effect talking about risk. In the case of future climate change, risk will be determined by the evolution of both hazards and vulnerability. Vulnerability will change as a result of a wide range of factors, perhaps most obviously economic development, population growth and land use, changes in which are socially determined, with some more 'locked in' than others (see Yohe and Tol, 2002). The paper proceeds by outlining the sources of data on global disasters and discussing how important weather related disasters are within this reported data. We highlight the problems within such data of enhanced reporting over time, classification difficulties and other problems. We then develop risk indicators for climate-related disasters and demonstrate their evolution of the past century, concentrating on 1970-2000. We analyse and discuss the importance of these observations on the distribution of risk for adaptation to potential future climate change.

2. Global natural hazards data – what is the importance of climate?

The data we use are derived 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) as well as population data from the World Bank. We describe the EM-DAT dataset and its processing, and examine the reliability of the data in terms of coverage, representation of trends, recording practices and attribution of particular disasters to climate-related events. Finally we present the results of the risk study and comment on them within the context of considerations of vulnerability. This is only a first step in assessing risk. Once high-risk countries have been identified it is necessary to examine the vulnerability of different population groups at a sub-national scale in order to target resources for capacity building; adaptation funds will be useless if they are not employed in a process-driven fashion that takes into account the particular geographical, political, economic and social circumstances of the vulnerable groups in question. Furthermore, a country may have a low risk score, but contain highly vulnerable population groups that are not representative of the national population as a whole. Conclusions that particular countries are especially at risk therefore do not indicate that risk or vulnerability is concentrated exclusively in those countries, and analyses such as those discussed below should not be viewed as exclusive.

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.

In order to use the EM-DAT data for an analysis of climate risk, the dataset must be 'cleaned' in order remove disasters that do not have 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 damsite 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. The inclusion of epidemic data is contested. However, epidemics account for a small percentage of global disaster burden over the periods assessed (particularly the last three decades of the twentieth century), so do 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.

3. Construction of risk indices from EM-DAT

3.1 Principles and data constraints

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. The indices described below measure risk in terms of direct, short-term societal disruption due to displacement, trauma and death, rather than in terms of loss of capital.

The periods chosen were 1971-1980, 1981-1990 and 1991-2000. Decadal periods are sufficiently short that socio-economic trends are unlikely to result in large changes in vulnerability, but long enough to capture multi-year climate variability and therefore include a reasonably representative sample of climate-related disasters. While long return-period events may not be represented, countries at risk from short to medium return-period events will also be vulnerable when faced with longer return-period

events. While the chance occurrence of, for example, a one in one hundred year event during a recorded decade might result in an anomalously high score for a country, the use of three decadal periods should ensure that such anomalous results are detected. Such compromises are unavoidable in this kind of analysis; more detailed assessments based on analysis of predictive vulnerability indicators and longer-term analysis of climate hazards will avoid these problems.

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.

3.2 Trends in recorded disasters and reliability of data

The broad trend in recorded disaster occurrence is one of increasing frequency in the latter half of the 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, suggesting that variations in recorded event frequency are not simply the result of the factors listed above.
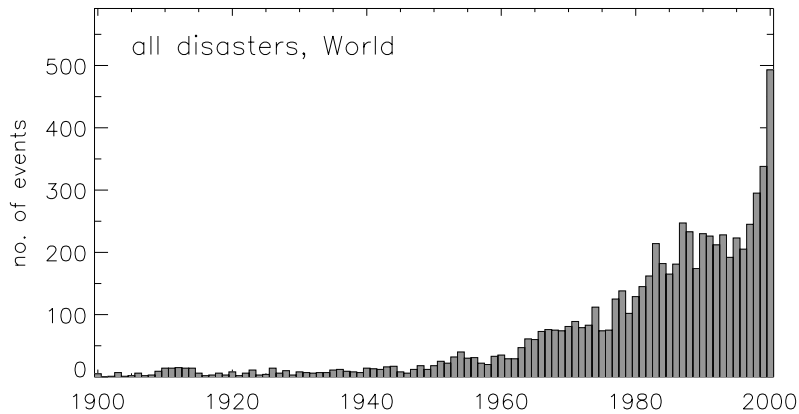
Figure 1. Annual global frequency of recorded climate-related disasters for all disaster types.
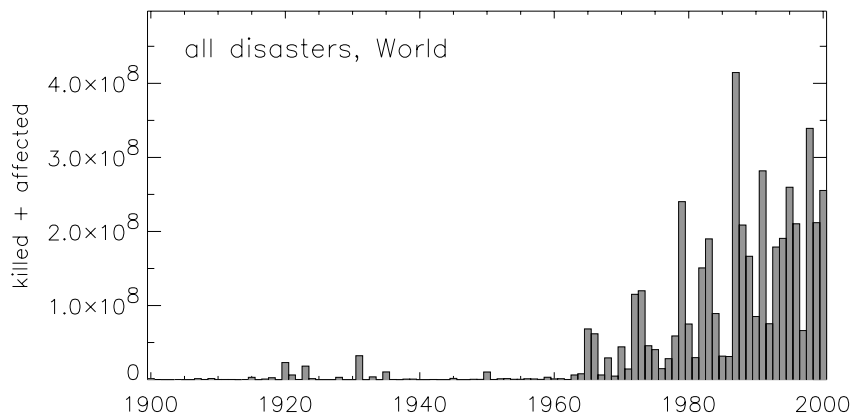

Figure 2. Annual sums of numbers killed and affected by all climate-related disasters worldwide.

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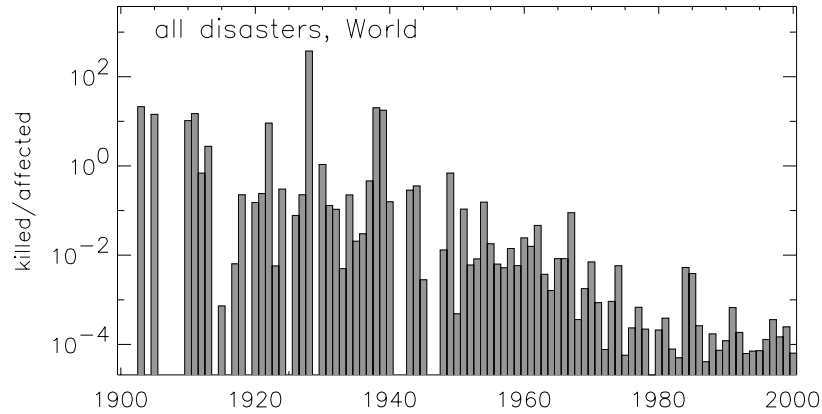
Figure 3. Annual ratios of worldwide total killed to worldwide total affected for all climate-related disaster types. Note logarithmic scale on vertical axis.
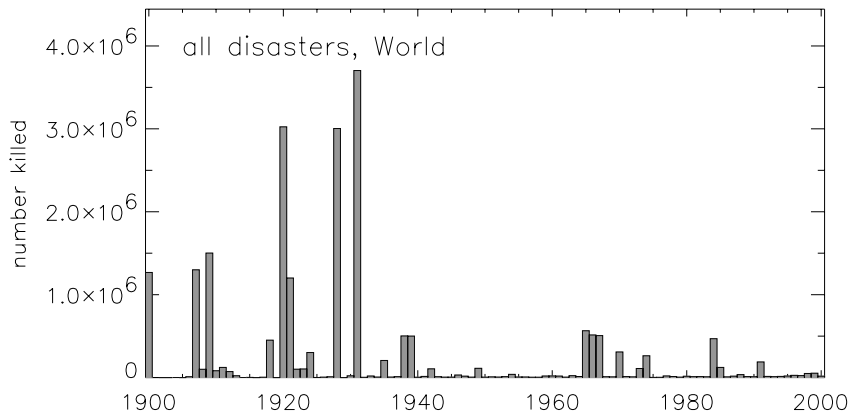

Figure 4. Annual worldwide totals of people killed by climate-related disasters.

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 patters – 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

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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.
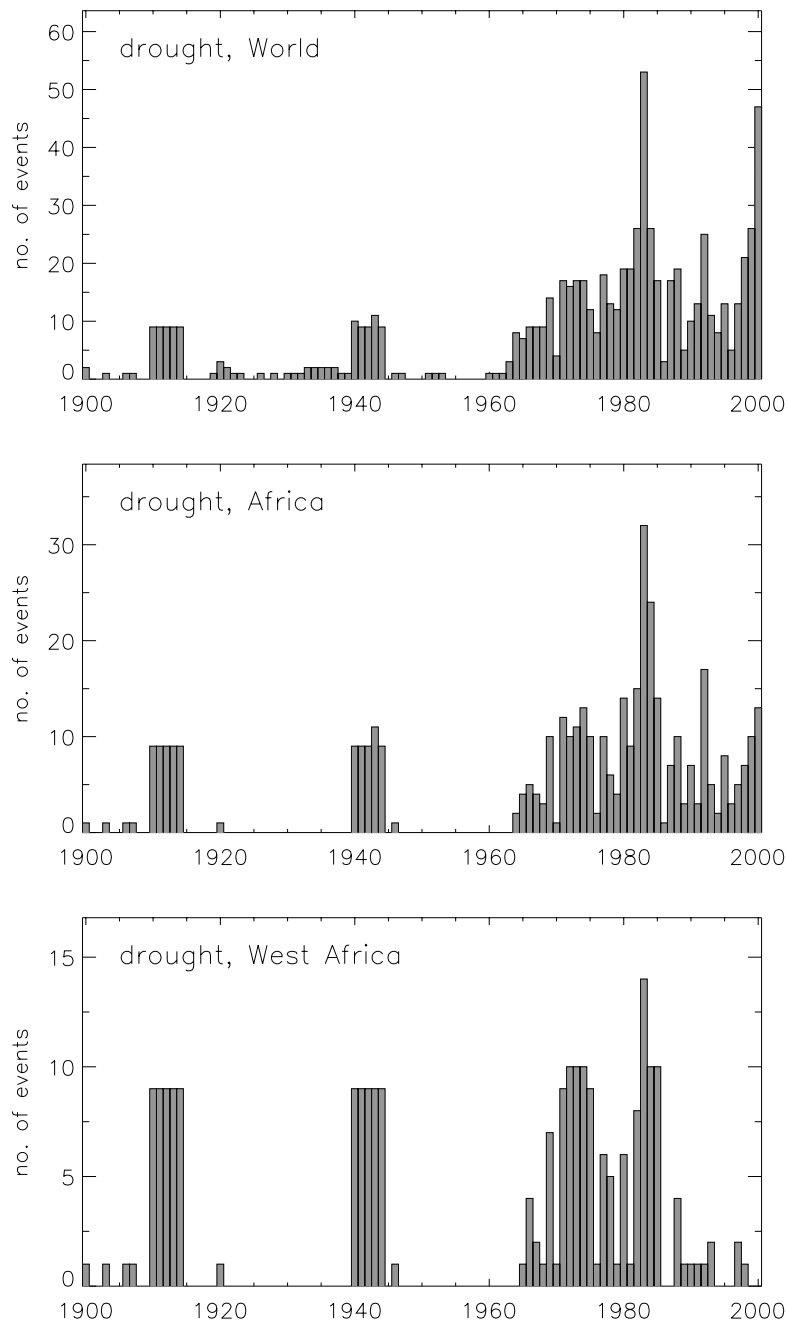

Figure 5. Drought frequency time series for the world, Africa and West Africa, demonstrating the significance of the Sahelian drought of the early 1980s, and earlier droughts in the 1910s and 1940s.

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, it appears likely that data relating to events occurring in the 1980s and 1990s are likely to be most representative of reality. While data coverage in earlier decades is less complete, certain countries are likely to have good records extending back a number of decades. However, for most countries, data for periods prior to the 1970s or 1960s are unlikely to be particularly reliable.

3.3 Vulnerability proxies

The above discussion of data reliability indicates that vulnerability assessments based on the disaster data 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. However, we are concerned with national-level vulnerability, and variations in data coverage between countries will be considerable, some having long records stretching back before 1950, 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.

From the point of view of assessing a country's level of risk, we use recent data that span a sufficiently long period that they include a number of extreme events that are broadly representative of the climatic variability to which that country is subject. Data relating to the period 1990-2000 are therefore 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 ranking of a country over these three periods also indicates that the results are 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.

We constructed a number of alternative national-level risk indices based on data for 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 RISK is the proxy measure for vulnerability, j refers to five alternative specifications outlined in Table 1, i = country i, and t = time period (1971-08, 1981-90, 1991-2000).

Table 1. 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 principal measure of risk with the greatest data coverage and arguably the most robust reporting is $RISK^1_{i,t}$ - numbers killed and affected, expressed as a percentage of the national population (using World Bank data) for the middle year in the 10-year period in question (i.e. 1975, 1985 and 1995). However, we also consider numbers killed as a percentage of population ($RISK^2_{i,t}$), absolute numbers killed ($RISK^3_{i,t}$), and ratios of killed to affected ($RISK^3_{i,t}$, $RISK^4_{i,t}$), as alternative measures of risk, and examine differences in the results obtained using these quantities.

4. Results

4.1. 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 2. 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 2 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 top twenty for all three periods. Antigua and Barbuda, Swaziland and Belize are

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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 $RISK^1_{i,t}$ is a reasonable proxy for vulnerability, yielding results that are relatively robust over time, at least for those countries with higher scores.

Table 2. 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*

4.2. 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 $RISK^1_{i,t}$ 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 $RISK^1_{i,t}$ 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 $RISK^1_{i,t}$ 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 $RISK^3_{i,t}$ 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 $RISK^1_{i,t}$ rankings between countries. Furthermore, in none of the periods examined are the twenty countries with the highest $RISK^1_{i,t}$ scores consistently represented by the best data coverage (Table 3). 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 $RISK^1_{i,t}$ 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 $RISK^1_{i,t}$ 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.
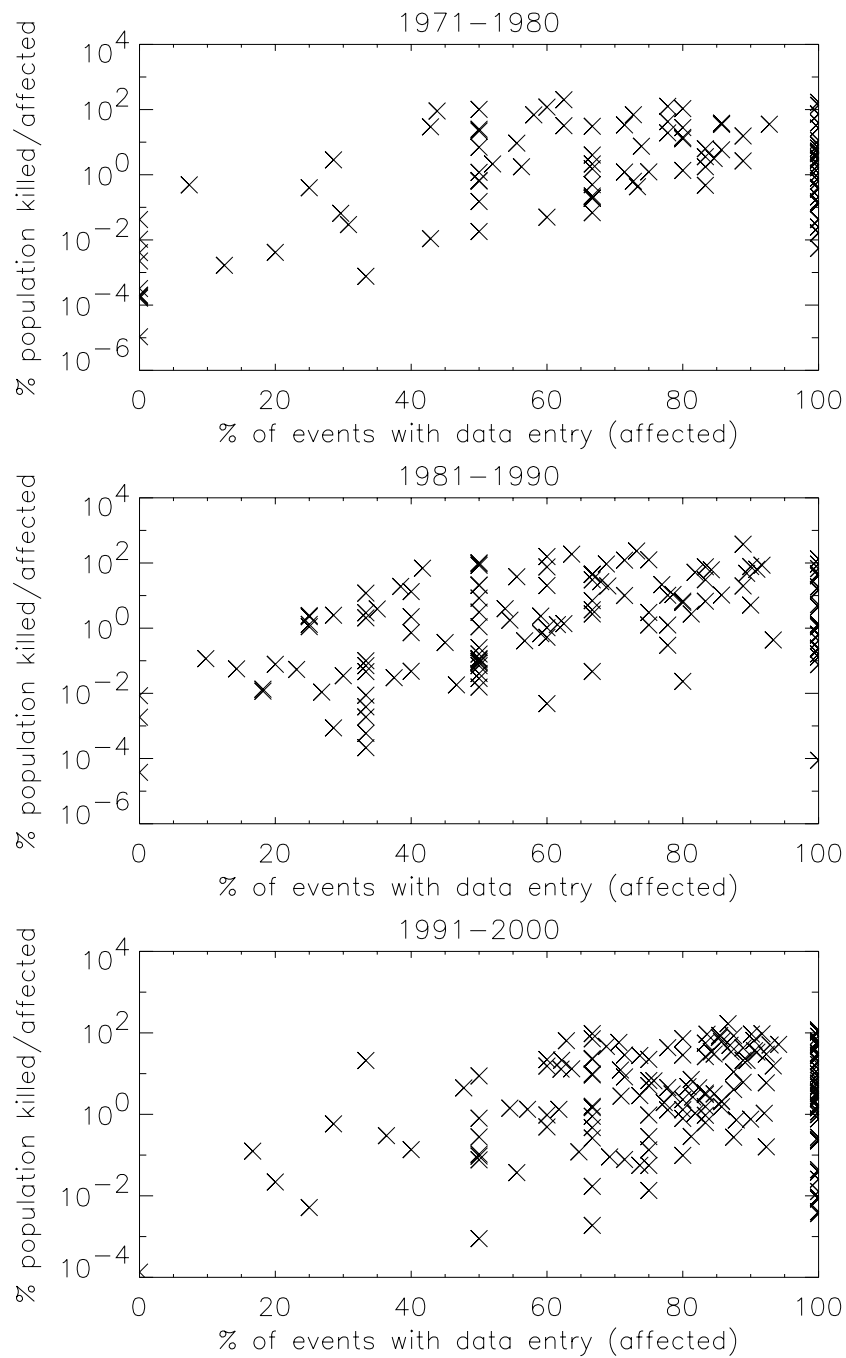
Figure 6. Scatterplots of RISK$^1_{i,t}$ scores versus percentage of recorded events with an entry in the 'total affected' category for the period in question. Each cross represents a single country. Non-zero values occurring at zero coverage are the result of data being present in the 'killed' category only.
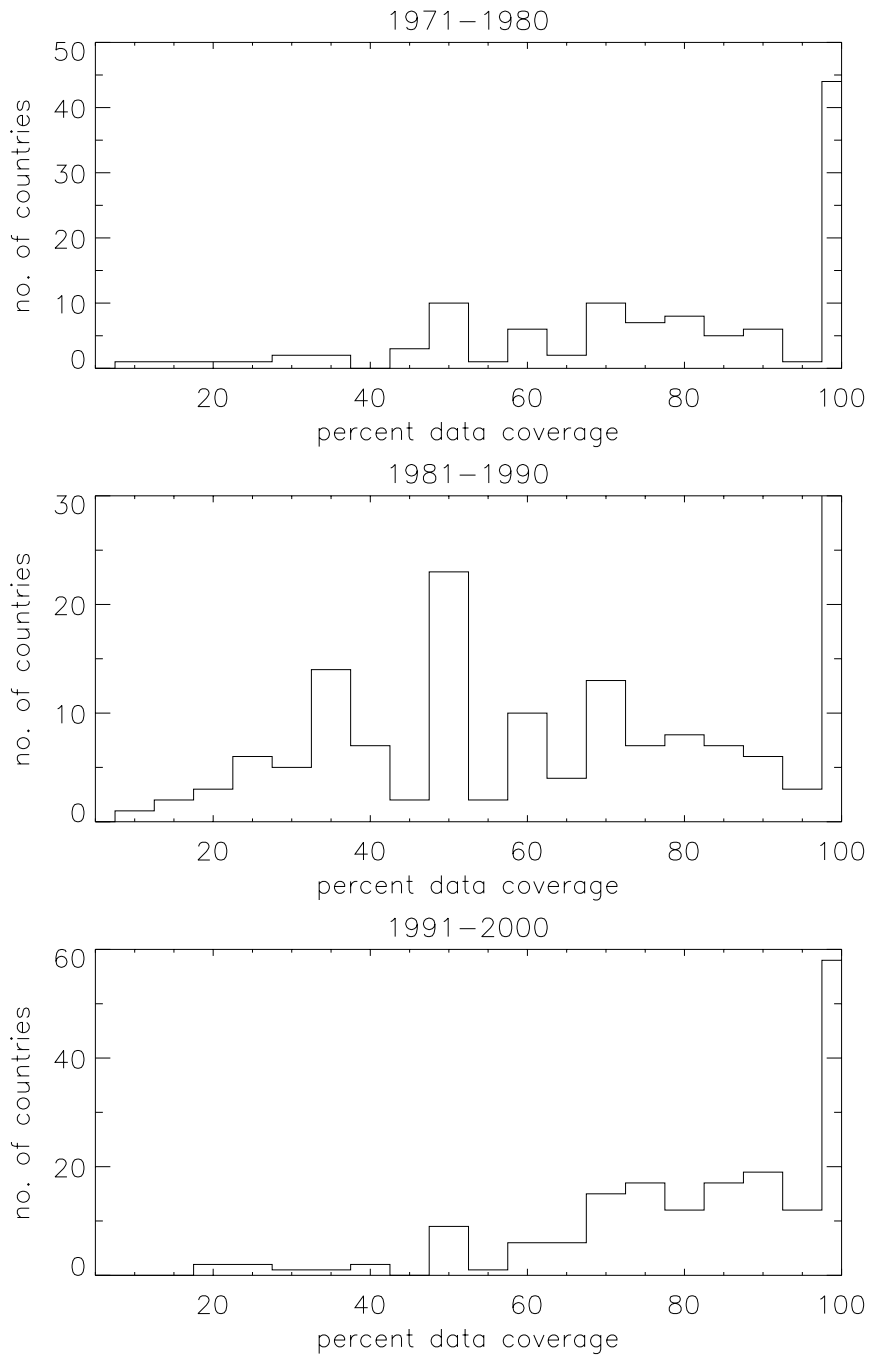
Figure 7. Distributions of data coverage for entries in the 'total affected' category. 100 percent coverage corresponds to all events having an associated entry in this category.

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Table 3: 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 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**

4.3. Other proxies for risk

4.3.1. Ratio of numbers killed to total affected

The other measures of risk listed in Table 1 yield additional information, complementing the 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 RISK$^1_{i,t}$ ranking. However, Australia is 88th in the ranking based on absolute numbers killed for the same period (RISK$^3_{i,t}$). Its positions in the rankings based on the two different ratios of killed to affected are 157 (RISK$^4_{i,t}$) (the second lowest non-zero score) and 124 (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 RISK$^4_{i,t}$ (calculated from killed and affected sums for the decade in question). Wealthy developed nations may score highly in the RISK$^4_{i,t}$ and 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.

4.3.2. Mortality data

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 4 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, Dominican 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 4. 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 1) are highlighted in bold.

Rank	1971-1980 RISK$^3_{i,t}$	1971-1980 RISK$^2_{i,t}$	1981-1990 RISK$^3_{i,t}$	1981-1990 RISK$^2_{i,t}$	1991-2000 RISK$^3_{i,t}$	1991-2000 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

5. Implications for adaptation to future climate

The determinants and nature of climate-related risk are important in terms of present-day intervention and risk reduction, and also for planning to meet the challenges of future climate change; a society's ability to cope with future climate change may be compromised if its vulnerability is exacerbated by existing climate hazards and their impacts. In the short term, the broad consensus following years of action and research under the UN International Decade for Natural Disaster Reduction (IDNDR) is that strengthening local capacity to cope with natural hazards such as flood and drought is an urgent priority, particularly in the poorest regions in the world (Few, 2003). There have been methodological advances in identifying and classifying underlying vulnerability to hazards, as well as to the multiple dynamics of economic and social change (Cutter et al., 2000; O'Brien and Leichenko, 2000; Leichenko and O'Brien,

2002. Yet the vulnerability of socially marginalized groups and the uneven distribution of risk within countries towards those excluded groups remains as entrenched as ever. The costs of disasters continues to rise in economic and human terms as a result (Pelling et al., 2002).

Part of the impetus for adaptation to changes in both vulnerability and in the climate itself over time comes from international policy processes such as the UN Framework Convention on Climate Change where funds for adaptation (e.g. through the Least Developed Countries Fund and the Special Climate Fund) have been proposed and implemented (see Dessai, 2002). But the data presented here on the current risks and vulnerabilities associated with present climate variability illustrate dilemmas in the design of response strategies to future risks. It can be argued that adaptation funding would be most effective and most equitably used if it were based on the specific objective of helping the countries and population groups most at risk from present climate-related disasters (see Paavola and Adger, 2002). Alternatively adaptation funds could be most effective if targeted to a set of countries that are likely to suffer most from the adverse impacts of climate change. Thus there is potentially a divergence between action for adaptation and action to cope with present risk. The interface between present adaptive capacity and future enhanced risk is a key element in both the international global climate change discourse and in other anticipatory planning for climate change.

But changes in hazard profile are also difficult to predict, given limited understanding of the complexities of the Earth's climate system and the difficulty of incorporating certain key processes into global climate models (Schellnhuber, 2000). Nonetheless, we can state with confidence that climate change is likely to be associated with changes in the frequency and severity of certain types of extreme event, driven largely by increases in baseline temperatures and sea-levels. For example, the IPCC (2001a) suggests that the peak wind and precipitation intensities associated with tropical storms are likely to increase. While there is no evidence to suggest that more tropical storms will occur, a greater proportion of them are likely to fall into categories currently classed as severe. Elevated sea-levels will increase the severity of storm surges in a similar manner. The IPCC (2001a) also reports that, while mean rainfall is likely to increase over many areas in the mid and high latitudes of the northern hemisphere, the frequency of extreme rainfall events is likely to increase everywhere, as will rainfall variability. Increased rainfall variability may increase the risk of drought and crop failure in semi-arid regions such as much of sub-Saharan Africa, and more frequent extreme rainfall events are likely to increase the likelihood of crop damage, flash floods and soil erosion.

Climate hazards are thus expected to increase in many parts of the world, particularly for developing countries, which are often located in areas of high rainfall variability or regions crossed by tropical storm tracks. For such countries, climate change is likely to mean more frequent and severe events of the type familiar from the recent historical record. Indeed it is likely that the recent historical record includes an anthropogenic climate change signal (Frich *et al.*, 2002). Furthermore, developing countries tend to be highly vulnerable to extreme events as a result of poverty, weak state institutions, and poor physical infrastructure (Pelling and Uitto, 2001). Climate-related disasters may further undermine a population's ability to cope with extreme events, such that vulnerability is exacerbated over time for particular social groups

(Kelly and Adger, 2000; Blaikie et al., 1994). Even without the threat of climate change, many developing countries would benefit greatly from adaptation measures designed to help them cope better with current climate variability.

Current risk associated with extreme climate events is therefore a reasonable proxy for risk associated with climate change in the near future. Countries that are unable to cope with current climate hazards will be the most poorly equipped to cope with the adverse impacts of climate change; any increase in the frequency or severity of extreme climate events is likely to exacerbate their vulnerability. Efforts to increase adaptive capacity and reduce vulnerability will be particularly useful when they are targeted at such countries. However, it must be recognised that future climate hazards may be qualitatively different in nature from those of the recent past for some countries. In particular, some low-lying small island states may in the worst case become effectively uninhabitable as a result of rising sea-levels (Lal *et al*., 2002; Barnett and Adger, 2002). Similarly, new hazards associated with the geographic displacement of climatic zones may render analyses based on historical risk somewhat redundant. Nonetheless, dramatic qualitative changes in climate are likely to occur in the medium to long term. The most immediate concern should be increasing people's ability to cope with near-term change, and indeed with current climatic variability (e.g. Adger, 1999; Adger et al., 2003; Cutter et al., 2000), and it is these results and perspectives that we believe to be important in this area.

6 Discussion and conclusions

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.

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