Global Change Impacts: Assessing Human Vulnerability at the Sub-National Scale.

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Abstract

The importance of adaptation to climate change is now widely recognized. Mitigation is not a sufficient response because time lags in the global climate system mean that no mitigation effort, however rigorous, will prevent climate change from happening in the next few decades (Huq and Klein, 2003). Already, all countries face many diverse challenges, and climate change provides an additional threat that adds to, interacts with, and can reinforce these, placing additional strains on people's livelihoods and coping strategies (World Bank, 2002). In an attempt to build preparedness for these global changes, and their interactions, new approaches to assessing human vulnerability to global change are needed.

The Intergovernmental Panel on Climate Change (IPCC) defines 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*" (IPCC, 2001). However, in the context of human societies, it is recognised that a key aspect of vulnerability is that it is spatially variable, reflecting local economic, social and cultural characteristics, as well as the local physical conditions and impacts brought about by climate change (floods, droughts, tidal waves, incidence of disease vectors etc). According to the World Bank (2002), "*the linkages of climate change impacts to poverty are dynamic, often inter-connected, and context-specific – reflecting geographic location; economic, social, and cultural characteristics; prioritization and concerns of individuals, households, and social groups; as well as institutional and political constraints*." The diversity of these many issues highlights the need to develop a holistic, integrated tool through which we can better understand the potential for change and adaptation at different scales. In an attempt to develop this, the Climate Vulnerability Index (CVI) has been designed. This is an index-based approach that draws together data from the bio-physical, economic and social sciences, and combines them in order to provide a holistic assessment of human vulnerability to changes in water resources.

In spite of the huge advances being made in climate modelling, with improved representation of processes at finer scales, there still remains a gulf between that and the community scale required for the understanding of socioeconomic vulnerability. As was clearly demonstrated in the case of the New Orleans floods in 2005, the poor are almost always those most susceptible to any kind of shock, and institutional systems may both counteract or exacerbate the impact of such shocks. This implies that to address human vulnerability effectively, it is essential to consider the conditions faced by the poorest parts of society, as these are not only likely to be most at risk, but they are also likely to be most in need of strategies for adaptation. In this paper, this novel index-based management and prioritisation tool is presented. As a means of illustrating the usefulness of this approach, a demonstration is provided of how it can be applied at regional, national and local levels, to address the very real spatial variations which exist in the face of global threats.

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1. Introduction

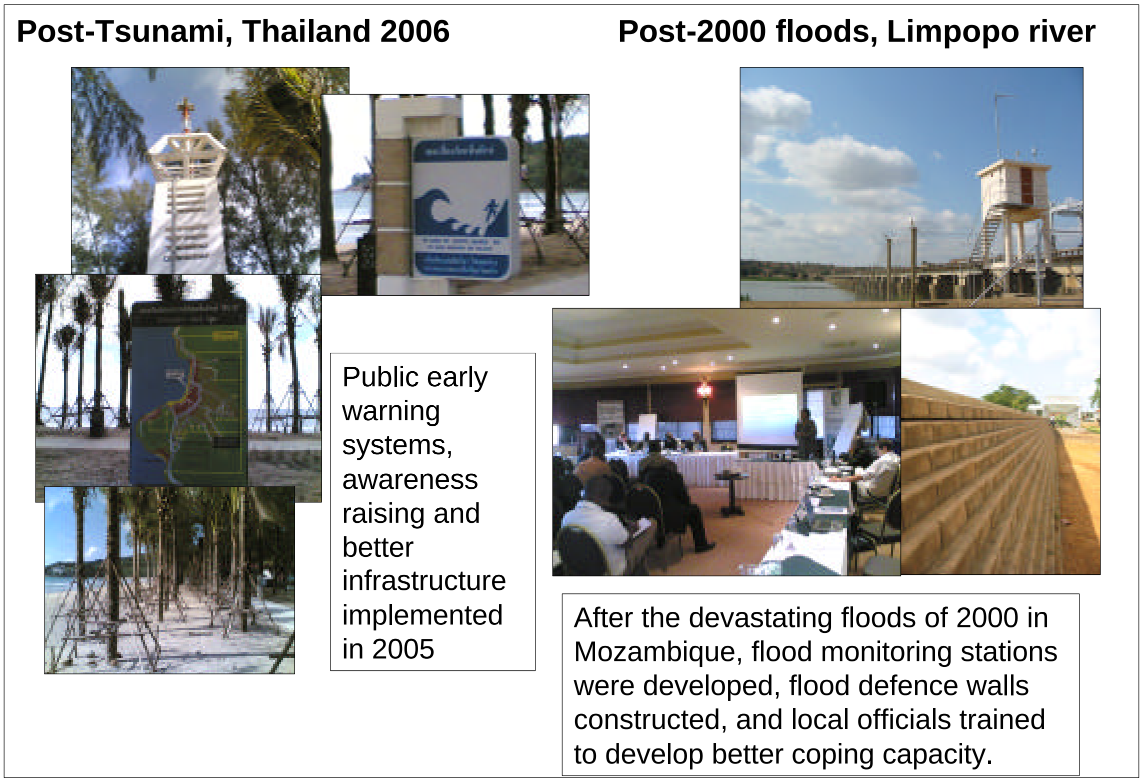
Indicators are a statistical concept which have been used for policy making since the 1920s. The use of indicators has been recognised as important in attempts to understand the complexities associated with environmental monitoring and management. The value of indicators for policy making is particularly useful when considering complex issues which are otherwise difficult to assess. A composite index approach, as used in the construction of the Human Development Index (HDI), is useful as a means to facilitate a more holistic understanding of a specific problem, although of course it cannot be seen as a perfect measure (Streeten, 1994). Certainly, the now widespread use of the HDI has brought about a revolution in the way we think about the development process, and indeed the creation of the Millennium Development Goals (MDGs) would not have occurred if the HDI had not provided its insights into the issues which underpin the real meaning of economic development as it affects individuals and communities.

2. Assessing vulnerability

When considering the issue of human vulnerability to global changes of all types, we need to consider information from a very wide range of domains. With respect to environmental vulnerability, SOPAC (1999) developed an index of environmental vulnerability, based on 47 variables, each measured on a scale of 1-7. An example of the composite index approach applied to water resource assessment is provided by the *Water Poverty Index* (Sullivan, 2002, Sullivan et al., 2002, 2003), and in this work, links between water availability and human wellbeing are examined. Based on a combination of conventional hydrological assessment techniques and the assets-based analytical framework of Sen (1985, 1999) and Chambers (1997), the WPI attempts to holistically capture aspects of hydrological, social, economic and environmental factors which result in a population being poorly served with water. Given the recognition that poverty is a key factor in vulnerability (IPCC,2001), and water is a key resource that we are all dependent upon, it is clear that there may be much merit in extending the Water Poverty Index for the purpose of human vulnerability assessment. Since climate change in particular is an issue of concern with respect to water resources planning, linking climate, water and vulnerability provides a fast-track indictor to identify communities and areas at risk. The hypothesis behind this work is that the use of an integrated, transparent structure for vulnerability assessment will make it more understandable to policy makers, and will contribute more effectively to targeting attention towards those groups who are most vulnerable.

Vulnerability relates to exposure to particular kinds of threats which can give rise to a reduction in human wellbeing. Throughout the world, people everywhere are vulnerable to both environmental and socio-economic shocks. Our ability to cope with these shocks determines how vulnerable we are, and any examination of historic catastrophes demonstrates that human vulnerability has social, economic and ecological dimensions. The degree of impact of any catastrophe is determined by our ability to adapt to changing circumstances in such a way as to reduce the impact of negative changes. This can be illustrated by comparing the human lives lost resulting from extreme events in 1999. In that year, 3 times as many such events were reported in the United States than occurred in Bangladesh, yet 34 times more people died in Bangladesh than in the USA (UNEP, 2000). This highlights two issues – the physical scale of the event, and the ability of the population to cope with it, both during, and after it occurs. Similarly, with respect to the recovery process associated with the Asian Tsunami of 2004, Thailand has been able to recover more quickly than Sri Lanka, reflecting both the resilience of the people and the strength of the economy, as well as the scale of the impacts themselves at the time of the event. This leads to the conclusion that the most effective way to reduce vulnerability is not to try to reduce extreme events which are likely to be beyond our control, but to increase coping capacity through training, awareness raising, and the utilization of technology. Examples of how these have applied in post-shock situations are shown in Figure 1.

Figure 1 Technological change and awareness raising. These go hand in hand to reduce human vulnerability.



For pragmatic reasons, vulnerability as outlined above needs to be defined in such a way as it can be measured within an index structure. To capture the essence of this definition of vulnerability, factors which give rise to vulnerable states need to be identified. In the structure of the *Climate Vulnerability Index* (CVI), indicators which represent the diverse dimensions of what makes a population vulnerable to climate and other global changes are explicitly incorporated. This provides a composite indicator to assess human vulnerability to water related impacts of climate change. The structure of the CVI incorporates six major components. These components have been identified following extensive consultation, and each can be represented by various subcomponents. The six major components are *Geospatial* factors, *Resource* availability and quality, efficiency of *Use*, *Access* to resources, *Capacity* to manage them, and *Environmental* impacts of that use.

For each of the variables used in all of the components, their selection for use would be made on the basis of how effective they are in locally expressing key aspects of vulnerability, as well as their practicality and data availability. It is intended that most of the data used for the calculation of the CVI can be found in existing sources. Water and environmental data can be derived from a range of local agencies and international sources. Economic data is available from a number of sources, both within countries and internationally. Social data can be taken from census records, health surveys, school enrolment rates, crime statistics and other local and national data sources. To classify the geospatial characteristics of different places, patterns of vulnerability within specific geographical types can be examined, and then generalized for wider application. On the basis of the collated data and the structure of the integrating framework, CVI values can be calculated for specific locations. A selection of possible variables to represent these components in a CVI assessment is shown in Table 1, but it is important to note that while the number of variables used in any index influences its sensitivity, different variables are both available and relevant at different spatial scales. For site-specific analysis, the specific selection of variables should be done in consultation with local people in the area in question, but it must be noted, if comparisons are to be made between locations, or over time, the same set of variables must be used.

Table 1. Potential variables for inclusion as sub-components of the CVI

CVI component	Sub-components / Variables
Geospatial (G)	• extent of land at risk from sea level rise and/or tidal waves • extent of land at risk from land slips • degree of isolation from other water resources and/or food sources • deforestation, desertification and/or soil erosion rates • degree of land conversion from natural vegetation • extent of risk from melting of glaciers • risk of glacial lake outbursts
Resource (R)	• assessment of surface water and groundwater availability • evaluation of the reliability of resources • assessment of water quality • dependence on imported or desalinated water • water storage capacity
Access (A)	• access to clean water • access to sanitation • access to irrigation coverage adjusted by climate characteristics
Capacity (C)	• expenditure on consumer durables, or income • the under-five mortality rate • existence of disaster warning systems • educational level of the population • percentage of people living in informal housing • GDP as a proportion of GNP • strength of municipal institutions • investment in the water sector as a percentage of fixed capital investment • access to a place of safety in the event of flooding or other disasters
Use (U)	• domestic water consumption rate related to national or other standards • agricultural water use related to the contribution of agricultural production to GDP • industrial water use related to the contribution of industrial production to GDP
Environment (E)	• livestock density • human population density • loss of habitats • flood frequency • Species loss

3. Calculating CVI values

The value of the CVI is a weighted average of all the components, although in the examples given here, the weights are all assigned a value of one. These weights here represent the degree (of risk of global change impact) associated with each variable. In practice, determination of the value of weights to be applied to an index such as the CVI should be achieved through participatory consultation and expert opinion. In this case, the weighting assigned should be related to the risk associated with the likelihood of climate impacts affecting each specific variable.

Once appropriate variables have been identified, and data assembled, the CVI values can be determined. The structure of the CVI can be written mathematically as:

$$CVI = \frac{r_r R + r_a A + r_c C + r_u U + r_e E + r_g G}{r_r + r_a + r_c + r_u + r_e + r_g}$$

where G, R, A, C, U, and E are *Geospatial, Resource, Access, Capacity, Use,* and *Environment*. Here, the weight given for each component is determined by a factor **r,** representing the risk that the component will be impacted by the conditions expected to arise due to climate variability or other global change. Initially, the risk factors **r** are all set to one, providing the opportunity for the establishment of a *'base rate CVI'*, but these risk factors could be used to focus on specific locally important issues. In practice, risk factors should be estimated from a detailed consultative exercise, and their application should be made explicit, to avoid manipulation of the values for political ends.

The procedure to estimate the CVI is outlined in Box 1, and the resulting CVI scores give a measure of vulnerability to existing climate variability at the present time, and allow comparisons to be made between different locations. The index values range from 0 to 100, with high values indicating high vulnerability. By applying scenarios of future conditions, the change in the CVI scores from the present values will indicate how different components of the CVI will impact on the selected aspects of human lives represented by the CVI components. This approach therefore provides a consistent and transparent methodology for the comparative assessment *over both time and space,* of vulnerability of human populations to climate change.

Box 1. Procedure for estimating the CVI

- Identify zones of present and likely future water stress.
- Identify geographical types likely to be vulnerable, select variables in the Geospatial component for each, and select sample locations within the geographical types.
- Collect and collate all relevant data for the sample locations.
- Construct scenarios of change in social, economic and environmental conditions to combine with estimates of change in water resources derived from climate impact assessments using Global or Regional Climate Model outputs.
- Calculate CVI scores for the present situation, and then under the combined change scenarios.
- Interpret the meaning of the CVI scores in terms of the impacts that they would have on people.
- Provide results at a range of spatial scales, incorporating some indication of uncertainty.

4. Implementation of the CVI

The CVI provides a globally generic approach which can be applied to any area. To provide a rapid approach by which the tool can be widely applied, it may be useful to consider broadly homogeneous zones representing different ecosystem types. These could include small islands, mountainous regions, semi-arid regions, low lying coastal zones, and urban conurbations. Each of these types has certain characteristics which will influence the ways in which the geospatial and other factors may be influenced by global change. As and example, some aspects of the vulnerability associated with mountain ecosystems are shown in Box 2.

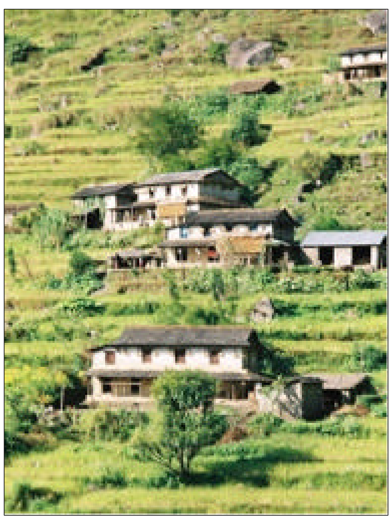
Box 2

Aspects of vulnerability within mountain ecosystems

More than half of humanity relies on the fresh water that accumulates in mountains – for drinking, domestic use, irrigation, hydropower, industry and transportation. *"As demand increases the potential for conflict over the use of mountain water grows. Careful management of mountain water resources must therefore become a global priority*" (Mountain Agenda, 1998). If mountains are vulnerable to climate variability and change, then it is not only those that live in the mountains themselves that may be impacted but all those within catchments downstream of them.

According to Haeberli and Hoelzle (2001) of the World Glacier Monitoring Service, the measurements taken over the last century "clearly reveal a general shrinkage of mountain glaciers on a global scale". The shrinkage of the world's mountain glaciers is a problem that has led to warnings of serious consequences for water resources (Worldwatch News Brief, 2000; IPCC, 1998; WGMS, 1998). It is envisaged that the accelerated melting of snow and glaciers will cause an increase in river levels over the next few decades, initially contributing to a higher incidence of flooding and land-slides (IPCC, 2001b; Greenpeace, 2001). Some predict that "glaciers in the region will vanish within 40 years as a result of global warming" and that the flow of Himalayan rivers will "*eventually diminish, resulting in widespread water shortages*" (New Scientist, 1999; BBC, 1999).

As a result of these kinds of changes, it is likely that mountain people, and those living down stream, will have to change their crop types and cropping patterns, and perhaps relocate or modify some of their infrastructure (such as water intakes, cereal mills, hydropower plants etc.). They will also be personally more at risk from landslides and flash floods.



Steep slopes make homes and livestock more vulnerable

Water mills such as this one are used by hill farmers to grind their cereals crops. If precipitation patterns change, traditional infrastructure such as this will be disrupted. Houses and farms already carved out of steep slopes may be more vulnerable to land slips and associated crop and property losses.

5. Data Collection and use

The data used to determine the CVI will be collected from a variety of sources, and will depend on the scale and resolution of the analysis being carried out. Ideally, to get the most reliable assessment, the finest possible resolution of existing data should be used. In practice, in most countries, the finest resolution economic and social data available is usually the *enumerator-district* level data, this being the smallest scale at which existing data is available from most national statistical services. This is usually the basis on which surveys are carried out for the purposes of national income accounting, population censuses, health and education surveys, etc. This can be coupled with data from other national and district data sources, and, where appropriate, from international agencies.

A range of international agencies are important as data sources for Water and environmental data. In the case of water resources, these are usually assessed on the basis of models built from point measurements taken from various locations within river basins. Most of the measurements used for hydrological assessment are generated from data collected by government agencies within countries, but in some cases, integrated data collection has been achieved for strategic reasons. For example, since the floods of 2000, the Limpopo river now has a river flow gauging process which is integrated to provide early warning of severe floods. Strategic reasons may also be the cause of a failure to integrate data, as is found in many parts of the world where flow data from different countries in transboundary basins does not match up. This situation occurs where countries view hydrological data as being of military importance, and so it is not disclosed. In recent years, some attempts have been made to build more integrated data at the international scale, to try to prevent some of the 'natural disasters' which have been seen for example in Bangladesh.

As a result of the work of international agencies, (eg the World Meteorological Organisation, UNESCO and others), estimates of gridded runoff are now available worldwide, and for large scale assessments, these values could be used and supplemented by information from local hydrological agencies. Similarly, a variety of information on different aspects of environmental status are available from international sources at a range of resolutions: water quality data are held by the Global Environment Monitoring System (GEMS); estimates of soil degradation can be found in UNEP (1992); and forest cover information from FAO (2001), among others. Topographic information, for instance, to assess areas of land at risk from sea level rise, would have to be obtained from topographic maps at suitable scales, and GIS softwere is becoming increasingly accurate. Remotely sensed data can also be of use, as well as specific studies which would provide information on individual issues or locations at risk. For studies at the sub-national level, sample locations within a specific geographical type could be chosen for data collection, in order to represent a wide range of physical, social and economic conditions. Again, this can often be collected from provincial or municipal agencies, but where local data need to be collected, a key aspect of the process should be the participation of local scientists, managers and stakeholders. Their involvement in specification of locally important criteria and variables, and in the collection and analysis of data would help to ensure that the results are relevant and acceptable to local people. This is particularly important when considering the capacity of local agencies to carry out such assessments in future periods.

6. Applying scenarios of climate change

Through the application of scenarios of future changes, the CVI can become a more dynamic modeling tool. Changes in the CVI values need to be based on assumptions about future social, economic and technological driving forces, as well as climate change. In the development of the CVI, four possible future world scenarios have been considered: *Markets First, Policy First, Security First,* and *Sustainability First* (UNEP, 2002). In this paper, the CVI methodology is demonstrated, using the *Policy First* scenario, and it must be noted that results from the application different scenarios would produce different results. A summary of the *policy first* scenario is shown in Box 3.

Box 3. Characteristics of various UNEP Scenarios

Markets First Most of the world adopts the values and expectations prevailing in today's industrialized countries. The wealth of nations and the optimal play of market forces dominate social and political agendas. Trust is placed in further globalization and liberalization to enhance corporate wealth, create new enterprises and livelihoods, and so help people and communities to afford to insure against – or pay to fix – social and environmental problems. Ethical investors, together with citizen and consumer groups, try to exercise growing corrective influence but are undermined by economic imperatives. The powers of state officials, planners and lawmakers to regulate society, economy and the environment continue to be overwhelmed by expanding demands.
Policy First Decisive initiatives are taken by governments in an attempt to reach specific social and environmental goals. A coordinated pro-environment and anti-poverty drive balances the momentum for economic development at any cost. Environmental and social costs and gains are factored into policy measures, regulatory frameworks and planning processes. All these are reinforced by fiscal levers or incentives such as carbon taxes and tax breaks. International 'soft law' treaties and binding instruments affecting environment and development are integrated into unified blueprints and their status in law is upgraded, though fresh provision is made for open consultation processes to allow for regional and local variants.
Security First This scenario assumes a world of striking disparities where inequality and conflict prevail. Socio-economic and environmental stresses give rise to waves of protest and counteraction. As such troubles become increasingly prevalent, the more powerful and wealthy groups focus on self-protection, creating enclaves akin to the present day 'gated communities'. Such islands of advantage provide a degree of enhanced security and economic benefits for dependent communities in their immediate surroundings but they exclude the disadvantaged mass of outsiders. Welfare and regulatory services fall into disuse but market forces continue to operate outside the walls.
Sustainability First A new environment and development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions. A more visionary state of affairs prevails, where radical shifts in the way people interact with one another and with the world around them stimulate and support sustainable policy measures and accountable corporate behaviour. There is much fuller collaboration between governments, citizens and other stakeholder groups in decision-making on issues of close common concern. A consensus is reached on what needs to be done to satisfy basic needs and realize personal goals without beggaring others or spoiling the outlook for posterity.

Source: UNEP (2002)

One of the challenges of model integration for policy development is the fact that timescale priorities are different for different stakeholder groups. For the purpose of estimating climate vulnerability at a policy-relevant time scale, changes by 2030 are assessed by addressing the possible changes in each component arising from projected levels of global climate change for that period. On the basis of the ecosystem type being considered, the geospatial components are modified according to potential risks. Example of possible risks relevant to different ecosystem types are shown in Table 2.

Table 2 Types of risks in different places

Characterising Risks For Different Ecosystem Types		
Urban settlements	**Mountain areas**	**Small Islands**
• **Population density.** Indicates the extent to which populations may be subject to increased health risks and the risk of infrastructure failure. • **Proportion of food and other resources brought from outside** Another way this could be measured is through an assessment of the ecological footprint (Rees, 1996). • **Population living in informal housing** Households in temporary shelters are particularly vulnerable to extreme events • **Municipal capability. T**he degree to which municipal systems are able to cope with the extreme events which are likely to occur in the event of increased climate variability. • **Extent of populations at risk from sea level rise. C**aptures the risk of loss of land area and the destruction of houses and infrastructure, and those parts of the city where serious pollution of water supplies might occur. • **Dependence on water storage.** Potentially measured in terms of water storage per capita, serves to indicate the degree of water security (or lack of it) for urban populations.	• **Slope.** Steep slopes which results in thin soils, rapid runoff and vulnerability to landslides. Slopes also make access to water difficult as it requires carrying water from valley streams up the hill-side to villages and gardens. • **Altitude**, expressed by the mean elevation of the mountain zone. Access to water resources in mountains may vary seasonally, and the flow regime may be dominated by glacial melt, which may change if the climate gets warmer or more variable. • **Degree of soil degradation and/or loss of natural vegetation.** These are important factors which are particularly relevant in mountains, bringing not only increased risks of flooding, but soil loss, and environmental change. • **Temperature.** This is a variable which is associated with the higher risks of flooding and landslides in mountains.	• **Extent of land at risk from sea level rise.** The land area at risk is the zone near the shore, reflecting vulnerability to sea level rise. • **Population at risk from sea level rise.** The proportion of the total population living in the risk zone. • **Isolation index.** This would be constructed from both the distance to the nearest continental land mass or island group and from the land area of the island (or island group) itself. • **Dependence on water storage.** This could be expressed as the amount of storage in relation to the annual demands

7. Potential outputs from the application of the CVI

A distinctive feature of the CVI is its applicability at a range of spatial scales, and it has the capability for application at finer resolutions in order to reflect the true spatial variability of vulnerability, and the social and environmental issues associated with it. The work is designed to assist in more effective and accurate identification of vulnerable areas. This approach would need to be carried out in a participatory manner in order to make sure it is adapted to and acceptable in each country.

One of the major features of this approach is the fact that it is starts with the people, and then moves upwards through various disciplines, to climate change – ie it is a 'bottom up' approach. All other climate vulnerability approaches tend to move the other way, from large scale climate models downwards to the people. When this CVI approach has been discussed with end users, there is a general expression of support from them, suggesting that it is much 'more relevant and understandable'. It is in the refinement of this aspect of the work that this project can also contribute. There is a clear need for scientific information to be delivered in an effective way by users, and so it is with this in mind that this approach has been tested so far.

A further improvement in the field of vulnerability assessment that this work can contribute to is in the harmonisation and streamlining of relevant data collection. What data is collected in a country is determined by political will, and if policy makers can be shown the relevance of specific data, they will be more likely to support its generation by national statistical agencies. Streamlining analytical techniques to generate consistent measurement approaches has already been achieved in the economics domain (eg in the standard approaches as agreed by the UN on how national accounts are calculated). It is now time for such harmonisation of data collection and analysis to be achieved in the water sector, and raising awareness of this need is important and essential. If this data harmonisation can be achieved, it has potential to contribute to the process of developing more effective national accounting practices (and thus costing) for water use. This is an essential feature of any effort to actually achieve *sustainable* water management, in the full sense of the word.

8. Illustration of the CVI approach

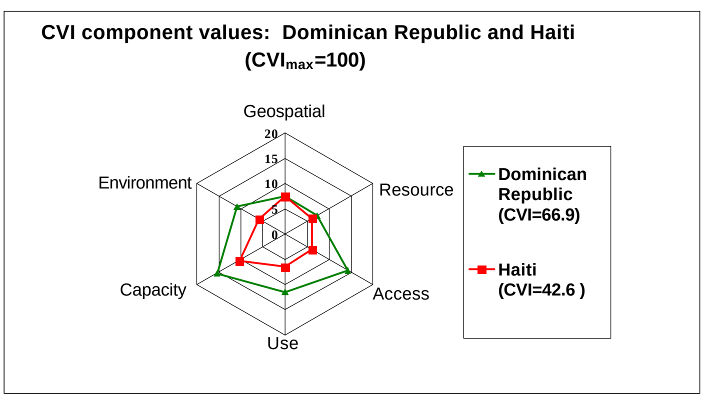
In order to get a holistic understanding of what the CVI can reveal, a graphical representation is used to show the values of each component simultaneously. This helps in the transmission of this complex information, and presents it in such a way that policy makers and other end users can see quite easily what the various strengths and weaknesses of each location may be. During the development of this tool, illustrative CVI values for selected locations have been generated using national data from public sources. This approach has been applied to mountain zones, urban developing cities, and small island states. Illustrative examples of the CVI scores for the Dominican Republic and Haiti are shown in Box 4.

Box 4.

Illustrating the effectiveness of the CVI

Recent hydro meteorological events have created serious damage to life and property in Haiti - much less in the Dominican Republic. The CVI suggested this before it happened, and it can demonstrate possible reasons why it is the case

Country	Geospatial	Resource	Access	Use	Capacity	Environment	CVI
Dominican Republic	7.5	7.33	14.30	11.45	15.38	10.93	66.90
Haiti	7.5	6.15	6.20	6.46	10.47	5.84	42.62

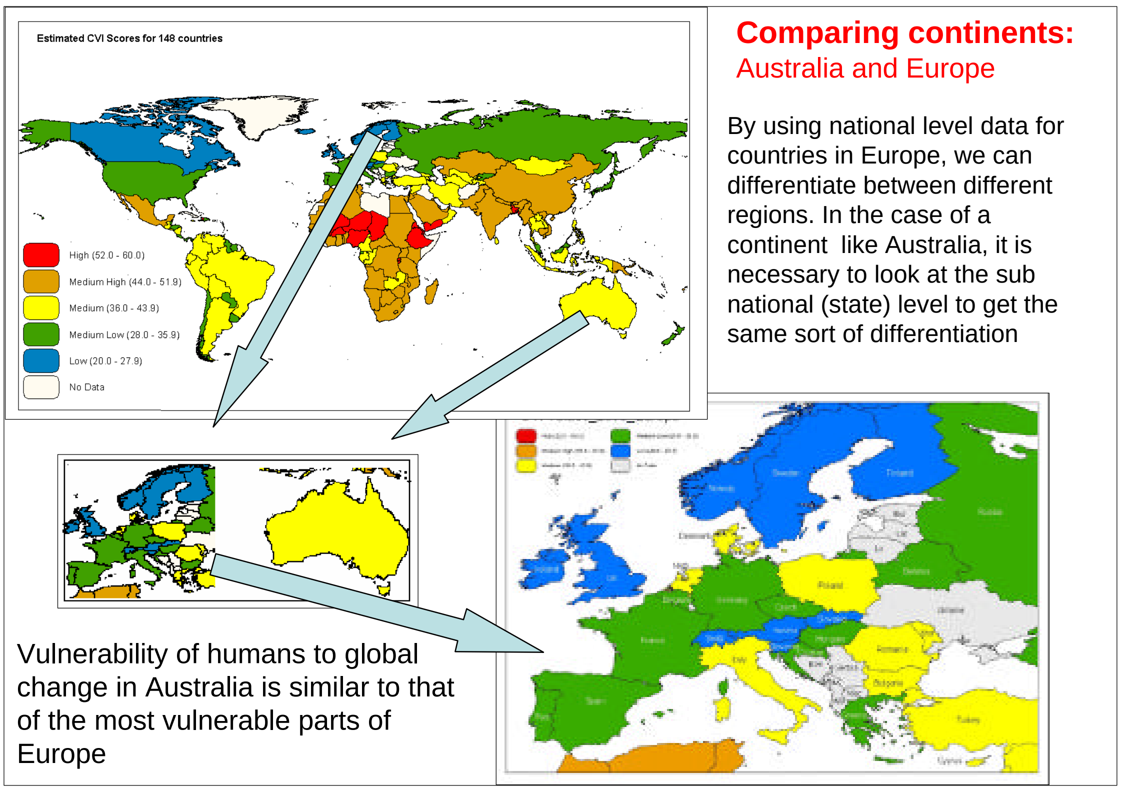


Graphical illustrations of the component scores make it easier for people to understand the message of the CVI

8.1 Global CVI values

At the national scale, the CVI approach has been applied to a total of 148 countries, and when this information is mapped, it is interesting to note that it clearly demonstrates regional variability across the world, with people in Africa by far the most vulnerable to climate change and other impacts. National level assessments of this type may be of use for example to donor agencies, international organizations etc., but smaller scale application of the tool is more useful in revealing spatial variations both within and between countries. In the case of a huge country like Australia, China or the USA, national values are almost meaningless, depending as they do on national average values for the relevant component data. To overcome this, sub-national level assessments are needed, and to illustrate this, a number of examples are provided here. In those parts of the world where countries are smaller, even national values can be useful to illustrate regional change, and the example provided below of Europe demonstrates how a large continental land mass can be assessed using finer resolution data. This is illustrated in Figure 2.

Figure 2 National values for smaller countries illustrate variations at the continental scale



While this figure illustrates the differentiation which can be made within regions on the basis of national level assessments, it also highlights that at this scale, the significant local variations found within countries will not be addressed. Local level assessment at the municipal scale is the most appropriate scale on which to base plans for local level adaptation strategies. This suggests that it is vital that municipal bodies are involved more fully in water management, and in particular in the implementation of *Integrated Water Resources Management*.

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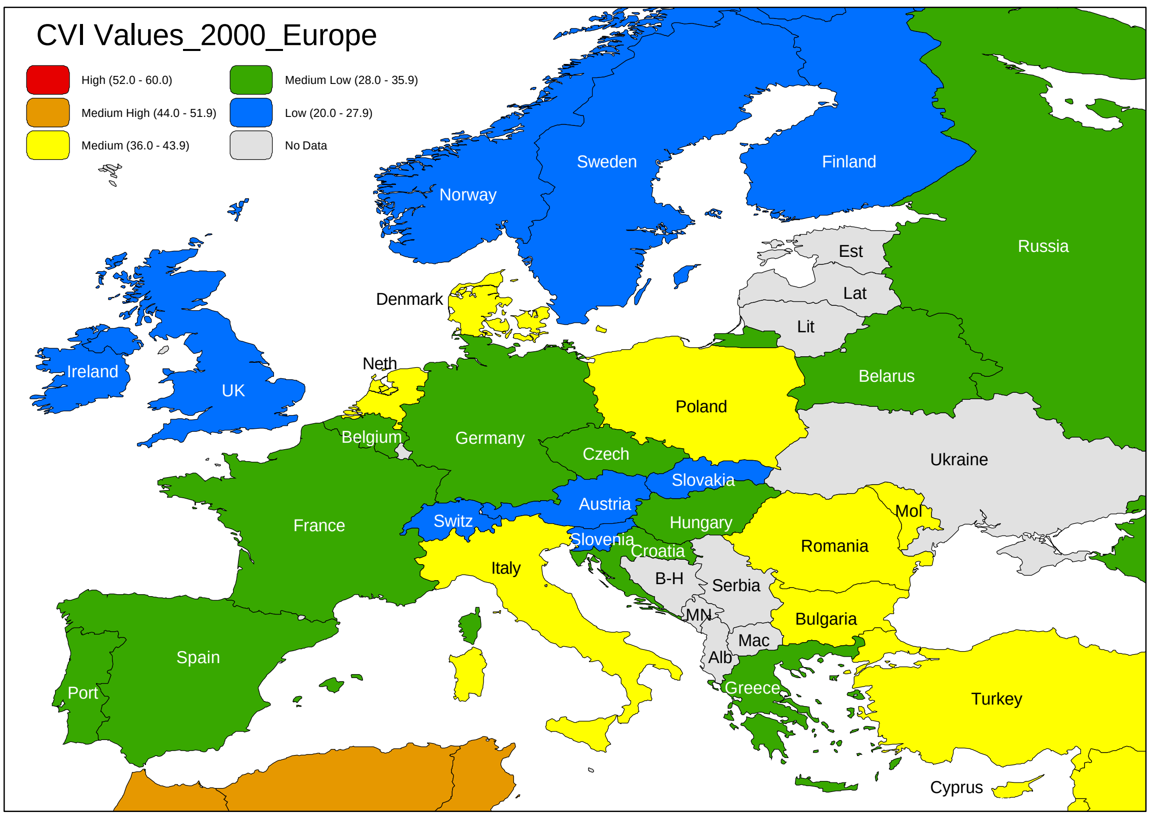
8.2 CVI scores across Europe

Application of the CVI approach to national level data for European countries clearly shows how some areas are more vulnerable to global changes than others. Figure 3 shows how current conditions (based on data from the year 2000) vary between different European countries, and how the vulnerability of those countries is significantly less than those in Africa. While the Northern countries in general have the lowest level of vulnerability at this national scale, both Denmark and the Netherlands face greater risks, mostly due to likely sea-level rise. Poland and the Eastern European states also have a higher level of vulnerability, and this is mainly due to poor institutional conditions and low capacity levels. In contrast, Italy, Cyprus, Turkey and many Mediterranean islands also have higher vulnerability, mainly due to their semi-arid climates and lower socio-economic conditions. This trend continues, with southern Mediterranean countries such as Morocco and Algeria having a medium to high level of vulnerability with desertification, high population density, and hydrological and political factors all contributing to worsening conditions in terms of water resources. While this assessment of vulnerability across Europe can be of general interest, assessments of this scale cannot address the very diverse conditions found within any one country. This can be illustrated by the case of the UK, which when assessed at this scale, appears to have a low vulnerability risk, yet at present, there are significant variations within that country, to the extent that drought orders and water use restrictions are in place in the South East of England, while other areas in the north and west have suffered from flash floods.

Figure 3 Current CVI values across Europe



8.3 Examining examples of the application of the CVI to small island states

The majority of the world's small island states are concentrated in tropical regions and are developing countries. Many have small land areas with high population densities, a limited range of natural resources and fragile resource base, a lack of skills and low economic resilience, and they are susceptible to hurricanes and tsunamis (Lal *et al.*, 2002). In their discussion of the special circumstances of small island states, the IPCC (2001) points out that, although they are not a homogeneous group, they tend to share many common features that serve to increase their vulnerability to the projected impacts of climate change. This combination of factors also usefully expresses the existing vulnerability of small islands. The common characteristics include:

- their small physical size and the fact that they are surrounded by large expanses of ocean;
- limited natural resources, many of which are already stressed;
- proneness to natural disasters and extreme events;
- relatively thin fresh water lenses that may be highly sensitive to sea-level changes;
- in some cases, relative isolation and great distance to major markets;
- extreme openness of small economies and high sensitivity to external market shocks;
- relatively large populations with high growth rates and densities;
- poorly developed infrastructure;
- limited funds, human resources and skills.

The potentially catastrophic effects of sea level rise on small islands has often been pointed out. Many islands have little land that exceeds 3 to 4 m above present mean sea level, and even on islands with higher elevations most of the settlements, economic activity and infrastructure are at or near the coast. Thus, sea level rise is expected to have a disproportionately large impact on economies and societies of many small islands (Lal *et al.*, 2002). In a summary of a workshop on climate change vulnerability and adaptation in Asia and the Pacific, Amadore *et al.* (1996) identify sea level rise as the greatest threat to small island nations, some of whose very existence is threatened. But the threats to water resources are also significant. Atolls in the Pacific are very sensitive to precipitation patterns and changes in storm tracks; traditionally, people have captured rainwater in cisterns, often located below the houses. In some areas however, introduction of piped water supplies has led to a conversion of some of these cisterns to an extra room in the house, increasing pressure on demand. This demand is mostly served from underground lenses of fresh water that ride on salt water, but these are likely to be diminishing, due to reductions in precipitation, and rising sea levels. In response, countries need to make water supply systems more robust by increasing storage capacity or by linking adjacent basins. However, this second option is often not a possibility for smaller islands. IPCC (2001) reinforces this view:

> "*The availability of water resources and food remain critical concerns in island communities. In many countries, water already is in short supply because islands (many of which are drought-prone) rely heavily on rainwater from small catchments or limited freshwater lenses*".

In some islands – raised coral atolls, such as Nauru and many of the islands of Tonga – the freshwater lenses may be no more than 10–20 cm thick, and they are the primary water source on several islands such as Kiribati (Burns, 2002). However, there is some controversy over the impact of sea level rise on water lenses. In contrast to the general opinion, some research indicates that there may be virtually no effect because the lenses could rise on top of the saline water. But, if combined with loss of land, the impact would definitely be negative. A recent study in Tarawa, Kiribati, concluded that the reduction in the width of the island by inundation could reduce the thickness of the freshwater lens by 29%, which combined with reduced rainfall, could reduce the volume of water in the lens even further (Shea *et al.*, 2001). Increasing rainfall intensity may lead to increased flooding, and the occurrence of precipitation as shorter more intense events could reduce recharge of freshwater lenses as water runs off more rapidly into the sea (Jones *et al.*, 2000).

On the basis of the issues raised above, preliminary component and CVI values for the present situation (2000) and for the year 2030 for four small island countries are shown in Table 3, following the *Policy First* scenario (UNEP, 2002). The selected islands represent a variety of conditions which may be found in a number of parts of the world. A number of approximations and simplifying assumptions have been made to generate these data, so the values must be treated as an illustration only[1]. For simplicity, the *Policy First* scenario has been used because this means it can be assumed that the Millennium Goals on access to safe water and on health (massive reductions in under-5 mortality) may be met[2]. This means that the Access and Capacity components improve enormously in the poorer countries (Comoros and Trinidad), while in the others they do not change a great deal as they are already well served. Overall, the results show that the poorest country, Comoros, is the most vulnerable under present conditions. In the future, the results indicate that it will remain the most vulnerable, but the increase in vulnerability for the other countries will be much larger. This is especially so for Bahrain, where there is a relatively large extent of land at risk from sea level rise, coupled with groundwater depletion, saline intrusion and population growth. With other scenarios, where we would assume that Millennium Goals are not met, vulnerabilities would show a larger increase in all cases.

[1] For present conditions, the CVI component values are derived from the equivalent WPI components, except the Geospatial. This is a combination of an isolation index (based on distance from the mainland and land area) and the extent of land at risk from sea level rise (approximately estimated from available topographic maps). The changes in the components were based on the Policy First scenario, and estimated as follows:

- Resources – change in runoff from IPCC (2001b, page 202) based on model results generated from the HadCM3 global climate model, combined with changed populations using annual growth rates derived from WRI (2000). A small arbitrary change in variability is also assumed.
- Access – based on change in access to safe water assuming the UN Millennium target for 2015 is met, and then that the same target is applied again and met again. The target is to half the proportion of people without access; thus by 2030, the proportion of people without access would be 25% of the value in 2000.
- Capacity – based on the combination of change in under-5 mortality rates and GDP, with equal weight given to each. For under-5 mortality rates the Millennium target is used in the same way as for Access. The target is to reduce the rates by two-thirds; thus by 2030, the rates would be 11% of the 2000 value. It is assumed that GDPs stay the same in comparative terms between the countries.
- Use – is changed only by the ratio of change in population.
- Environment – the natural capital index values from GEO-3 (UNEP, 2002) for the region or sub-region as available are used.
- Geospatial – some of these variables are such that they would not change much over time, but other possible variables could be very sensitive to global changes.

[2] There are many today who consider the achievement of the MDGs by 2015 as unlikely, but for the purpose of this analysis, we shall assume they are met.

Table 3 Preliminary CVI values from national data for some small island States

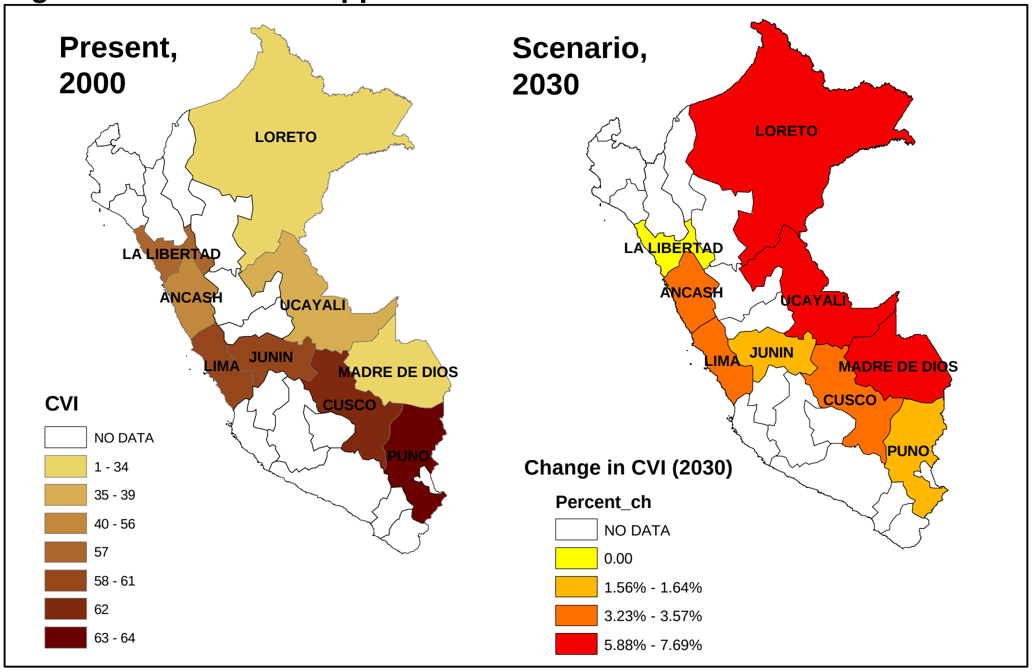
Country	Year	Geo-spatial	Res-ources	Access	Cap-acity	Use	Environ-ment	CVI
		Component values						
Bahrain	2000	38.5	94.2	3.0	13.1	63.6	45.6	43.0
	2030	**38.5**	**107.8**	**0.8**	**10.2**	**82.6**	**58.2**	**49.7**
Barbados	2000	35.8	67.8	0.0	10.2	46.3	45.6	34.3
	2030	**35.8**	**78.5**	**0.0**	**8.8**	**53.6**	**53.2**	**38.3**
Comoros	2000	29.1	69.6	62.0	43.7	57.2	45.6	51.2
	2030	**29.1**	**84.2**	**15.5**	**31.1**	**86.5**	**58.6**	**50.8**
Trinidad and Tobago	2000	22.8	58.0	12.0	23.0	58.4	53.8	38.0
	2030	**22.8**	**68.0**	**3.0**	**19.7**	**67.5**	**62.8**	**40.6**

Note: Higher values indicate higher degrees of vulnerability. The values shown here are included for illustration of the CVI methodology only; they do not indicate any statement on the part of the authors about the countries concerned.

8.4 Applying the CVI at the sub-national (district) scale: an example from Peru

Figure 4 illustrates the application of the CVI to a number of departments in Peru. In this case, the CVI methodology has been applied at the sub national scale, and through the application of the likely changes resulting from the *policy first* scenario, this illustrates how people in different parts of the country are likely to be more vulnerable to global changes than those in other parts. The areas currently most vulnerable to the impacts of climate and other changes are those of high population density and steep slopes, while in the future, those districts most likely to suffer negative impacts of such changes are those areas which are currently being targeted for natural resource exploitation (oil, timber), and consequent inward migration. This information is useful for the purpose of targeting coping strategies, and building capacity for adaptation and change.

Figure 4 Sub-national application of the CVI: Peru



8.5 Applying the CVI at the community scale: urban and peri-urban areas.

Vulnerability in urban areas has been recognized in a number of ways, with urban areas identified as potentially those which may have the highest level of water related vulnerability for humans (Hardoy et al, 2001, UNCHS, 2001). Currently over 50% of the world's population living in either urban or peri-urban areas, and there is clearly the need to consider how such populations may be impacted upon by climate variability and change. There is little doubt that as the 21st century progresses, urban growth will continue, especially in the developing world, and growth rates of around 2% per year are expected in urban areas over the next 15 years, although after that time, rates are expected to decline. The high urban growth rates currently seen are due not only to natural growth, but also to the attractions offered by urban areas in the form of increased employment opportunities and better public amenities, as well as the factors tending to drive people out of rural areas, such as land degradation and political conflict (UNEP, 2000). These growth patterns have resulted in an increasing number of mega-cities, such as Jakarta, Mexico City and Lagos, but in the future, urban growth is expected to take the form of an increasing number of more moderately sized cities rather than huge agglomerations (UNCHS, 2001). One of the major ways in which these populations will be affected will be in terms of increasing stress on water supplies (Cosgrove and Rijbersman, 2000; Falkenmark, 1990), and it is clear that this dependence on decreasing resources will have detrimental effect on the ability of people to generate livelihoods (Chambers, 1995, World Bank, 2001) and on their health (WHO, 1995).

Figure 5 Arusha, Tanzania. Typical conditions in urban areas of Africa

There are a number of common characteristics of urban populations which make them especially vulnerable. These include:

- high dependence on imported foods;
- high proportion of population in informal housing (especially in less developed countries), often in high risk zones (eg., on flood plains or in deep gullies);
- low priority on environmental issues in many municipal authorities;
- increasing reclamation of marginal land for use in urban development;
- severe resistance to drugs used to treat diseases such as malaria and TB;
- high density of population, which influences ease of disease transmission;
- overstretched infrastructure, especially water and waste systems;

- high dependence on water storage systems;
- high proportion of the population below national poverty lines;
- high dependence on natural resources for food and fuel;
- low levels of per capita savings;
- high levels of reliance on informal employment.

In addition to the factors above, there are a number of other issues which give cause for concern over the wellbeing of human populations in the face of climatic variability. One of the most significant of these is the fact that many of the world's biggest cities are historic ports located at or very near sea level. Examples include: Karachi, Lagos, Calcutta, Bombay, Shanghai, Bangkok, Rio de Janeiro, Buenos Aires, Dar es Salaam, Los Angeles and Tokyo (UNCHS, 2001). Together these represent hundreds of millions of people, many of whom could be severely affected by rising sea levels. There is also the risk that increased climate variability will lead to more tsunamis which could hit these high concentrations of population. Potential changes in global ocean currents and wind patterns could be factors that increase the incidence of dangerous smogs, exacerbating the already poor air quality found in many cities (WHO, 1992). One of the reasons for this high risk is that a high proportion of the population in large developing cities depend on biomass fuels for their cooking needs (Hardoy *et al.*, 2001). A further issue is the fact that cities usually generate a proportionately larger contribution to GDP than rural areas, so that disruption there is likely to have a significant impact on macro-economic performance, increasing overall levels of national vulnerability.

The CVI approach for urban areas is illustrated here by drawing on WPI data at the community level from six urban or peri-urban areas in three countries (from Sullivan *et al.* 2002). As before, a number of approximations have been made in this preliminary analysis, but Table 4 illustrates preliminary component and CVI values for the present situation (2000) and for the year 2030, following the *Policy First* scenario.

Table 4 Preliminary CVI values for some urban and peri-urban communities

Community	Year	Component values						
		Geo-spatial	Res-ources	Access	Cap-acity	Use	Environ-ment	CVI
South Africa								
Wembezi (informal)	2000	19.6	71.9	51.2	53.9	82.0	60.9	56.6
	2030	**25.7**	**106.4**	**12.8**	**44.4**	**93.8**	**78.3**	**60.2**
Wembezi (formal)	2000	19.6	71.9	13.5	22.0	61.9		37.8
	2030	**25.7**	**106.4**	**3.4**	**18.1**	**70.8**		**44.9**
Tanzania								
Majengo	2000	31.4	63.1	67.3	37.1	85.0	1.6	47.6
	2030	**27.6**	**81.8**	**16.8**	**23.7**	**125.9**	**2.1**	**46.3**
Kijenge	2000	31.4	63.1	46.1	31.7	78.4		50.1
	2030	**27.6**	**81.8**	**11.5**	**20.3**	**116.1**		**51.5**
Sri Lanka								
Awarakot-uwa	2000	39.6	62.5	64.8	20.4	78.8	71.9	56.3
	2030	**44.7**	**73.2**	**16.2**	**19.4**	**97.4**	**101.7**	**58.8**
Tharawath-tha	2000	39.6	62.5	73.5	49.4	83.8	57.8	61.1
	2030	**44.7**	**73.2**	**18.4**	**47.0**	**103.6**	**81.7**	**61.4**

Note: A number of simplifying assumptions have been made to generate these data, so the values must be treated as an illustration only[3]. They do not indicate any statement on the part of the authors about the locations or countries concerned.

From Table 4, it can be seen that, based on these assumptions, the urban populations in Sri Lanka currently have the highest CVI scores, indicating the greatest degree of vulnerability to climate variability out of this sample of locations. Access is poor and population densities are the highest of the sample shown here. The location at least risk is the formal settlement in Wembezi, South Africa, which contrasts markedly with the informal settlement in the same area. This highlights the importance of the access and capacity variables in terms of reducing the vulnerability of the poor, since the two places are very close together and have the same resources and degree of geospatial risk. The data on the future CVI values show a similar pattern, but the increase in vulnerability is greatest in South Africa. This seems to be mainly due to declining resources, combined with increasing urban populations and dependence on imported food. While it must be noted that these values are illustrative only, they do differentiate between the various urban zones, demonstrating the validity of assessing the CVI at the local scale, as well as at national scales.

9. Conclusions and Recommendations

The application of the Climate Vulnerability Index provides a powerful technique to express the vulnerability of water resources to climate variability and climate change in a systematic way. It is a holistic approach which integrates physical, social, economic and environmental issues. The results are simple to understand – for instance, they can be presented as a single number to represent the vulnerability index for a particular location – but at the same time, the underlying data can be examined, and the whole process is open and transparent. The outputs can be linked directly to impacts on people through the application of the sustainable livelihoods framework and the poverty implications can be examined. There is little doubt that the poor are the most vulnerable to the impacts of climate variability, and that they will be the most affected by climate and other global changes. The identification of zones of vulnerability provides a systematic

[3] The CVI component values are based on local data, and the changes in them are derived in a similar way to the national level examples. Except for the resources component, the scenario changes are determined at the national or regional level, rather than being specific to the local situations. Variations are as follows:

- Resources – runoff values are from UNESCO (1997) and Sullivan *et al.* (2002); the changes are estimated as before.
- Capacity – the proportion of the population living on less than $1 a day is used to indicate degree of financial vulnerability, instead of GDP, from World Bank (2001).
- Geospatial – uses a combination of four variables: consumption of traditional fuels to indicate the degree of dependency on natural resources (vulnerability to disruption of supplies), from UNCHS (1996); population density to indicate the degree of pressure on resource systems, from World Bank (2001); urban population as a percentage of the total to indicate pressure on infrastructure systems, increased health risks, etc, from World Bank (2001); and cereal imports per capita to indicate dependence on food from external sources (vulnerability to trade shocks), from World Bank (1995). Changes in geospatial variables (based on the Policy First scenario) were estimated as follows: By 2030, we can anticipate that there will be a significant reduction in the consumption of traditional fuels. This is because there will be less available and new technologies should be in place, especially in urban areas; a 2% reduction per year is assumed. Population density is likely to increase in all areas, particularly urban ones, as population growth occurs over the next 30 years. It is assumed that the increase will be 1% annually. The same assumption is applied to the changes in urban populations as a proportion of the total. Based on the Policy First scenario, an increase in the import of food, indicated here as imports in cereals, is anticipated. This is likely to occur following rises in population, and the possibility of increases in the comparative advantages in cereal production experienced by specific locations. For the purpose of this illustration, an assumption is made that an increase in imported cereals will occur at a rate of 1% per year, continuing to aggravate vulnerability in areas dependent on food imports.

rationale for deciding on priority areas where proactive measures to protect populations should be taken.

The proposed approach is suitable for examining vulnerability to present levels of climate variability, providing a means of discriminating between different locations or communities. Also, through the application of change scenarios, it can be used to examine the impacts of climate change, by combining predicted climate scenarios with expected or possible changes in social, economic, technological and environmental conditions. Depending on the scale of the application, the data required to implement the CVI are mostly available from existing sources or can be collected with modest effort, making it a relatively straightforward process to implement at a variety of scales.

This applicability at a range of spatial scales is a distinctive feather of this technique.Global coverage can be achieved by working mainly at the national level. Even at this scale, some degree of discrimination within countries can be provided, because the method can be based on geographical types such as mountains, cities, or coastal areas. The CVI method also has the capability for application at finer resolutions in order to reflect the true spatial variability of vulnerability and the social and environmental issues which contribute to it.

It should be noted that the work presented here is work in progress. There is much scope for the methodology to be refined and tested further by more detailed study. The variables suggested here for inclusion in this index represent preliminary ideas, but there is a need for wider consultation with experts and stakeholders to finalise the approach. Similarly, the examples illustrated here are the result of a rapid analysis at the desk study level; they have been included to demonstrate the proposed methodology, and must not be taken as representative of the actual situations in the areas studied. An area of significant further work in taking this approach ahead would be how to generate specific future changes in measurable CVI components, based on generalised scenarios of how societies might change. A range of models can be applied and reasonable assumptions made to achieve this.

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