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Water resources, climate change and human vulnerability

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It is well recognised today that climate change is affecting the Earth's physical and biological systems, and is expected to do so on forthcoming decadal to century timescales. A need exists for useable predictions of the impacts associated with such climate change, and the likely societal responses to these. This must also be seen in the context of other drivers of global change, and be presented at suitable spatial and temporal scales, to enable prioritisation of adaptation measures which are feasible in the most vulnerable communities, countries and regions.

Climate modelling is advancing, with much better simulations able to explain observed changes believed to be a consequence of raised atmospheric greenhouse gas concentrations. Generated from 'ensembles' of climate model outputs, these are expected to have more robust predictive capability. Ideally, to link the biophysical and social scales, it will be necessary to characterize climate behaviour at spatial scales smaller than those of the current climate model outputs, and to include predictions of surface meteorological extremes which incorporate rainfall as well as temperature change. The challenge of this is ongoing. To gain fully from the improved climate change predictions now available, and to develop associated mitigation and adaptation strategies, well-founded socio-ecological-economic[1] models are required, integrating social and biophysical information to provide holistic insights into alternative possible futures. It is also important that these should be both accessible and relevant to the various users of such information, and presented in a way which is easy to understand and explain.

Climate vulnerability assessment is complex, touching on social, cultural and economic factors which need to be combined with the physical aspects of climate change. Many of the changing climate drivers of concern have a hydrological basis – floods, droughts, tidal waves, and humidity levels, this latter affecting incidence of disease vectors. In this work, we will focus on the impact of climate change on water resources and the knock-on effect this will have on human society. With improved representation of the global hydrological cycle, there is more potential to try to link clearer hydro-climatic information explicitly to human scale conditions. Furthermore, advances in computer power now allow climate models to operate at scales below 50 km^2, and processes that were hereto heavily parameterised (such as large-scale storms) can now be modelled more accurately. Despite this progress, there still remain many challenges in meshing together the climate and social sciences, and the very different conceptual foundations on which they are based.

In this paper, we present a policy-orientated approach which attempts to address this challenge, by drawing together data from the bio-physical, economic and social sciences, and combining them in order to make a holistic assessment of human vulnerability to climate and other drivers of global change. We have referred to this as the *Climate Vulnerability Index* (CVI), and we have taken water as a focus, as this is widely considered to be a key driver of human (and ecological) wellbeing. Further work will extend the CVI approach to examine other global impacts, such as disease incidence or agro-ecological changes, resulting from climate change.

By linking outputs from global climate modelling to the components which make up the CVI, we are able to suggest possible areas where vulnerability of water resources is likely to impact both on human livelihoods and on the generation of ecosystem services. We first present the generic methodology used in this approach, and we then provide a test-case based on the geographically differing administrative districts in Peru. The results provide insights into potential stress points, and, on this basis, it is possible to suggest what conditions of vulnerability exist in these different districts of Peru. Using such information, policy makers and other resource managers will be better able to determine what responses may be most appropriate in these heterogeneous conditions. This work is based on publicly available economic and social data, coupled with climate change data generated from existing simulations by global climate models.

Keywords: *Water resources, vulnerability, climate change, global change, Climate Vulnerability Index (CVI), Peru.*

[1] Socio-ecological-economic models are those which take account explicitly of social and economic information, but are bounded by bio-physical realities, as for example described in the physical Laws of Thermodynamics.

1. INTRODUCTION

The importance of adaptation to climate change is now widely recognised. Mitigation is not a sufficient response because the 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). The warming now being experienced is the result of emissions that took place decades ago, and the first impacts on natural systems are already being observed. It is, therefore, increasingly evident that, in addition to policies aimed at mitigation, it is also necessary to encourage those focused on adaptation to the effects of climate change. By adaptation we mean any adjustments in natural or human systems that take place in response to the actual or expected impacts of climate change, intended either to moderate harm or to exploit beneficial opportunities (IPCC, 2001b).

In this paper, we consider the vulnerability of human systems to climate change, mainly in relation to water resources, and in particular, we focus on the vulnerability of poor people in developing countries. 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, 2001b). However, poor people are vulnerable not only to climate change, but to many other drivers of change. More generally, the meaning of vulnerability can be considered to encompass exposure to risk, hazards, shocks and stress, difficulty in coping with contingencies, and access to assets. Poverty is now widely viewed as encompassing both income and non-income dimensions, including lack of income and other material means; lack of access to basic social services such as education, health and safe water; lack of personal security; and lack of empowerment to participate in the political process and in decisions that influence one's life. Since extreme vulnerability to external shocks is now seen as one of the major features of poverty (UNDP, 1997), such shocks may include indebtedness, HIV/AIDS, food insecurity, environmental degradation, the impacts of global trade, conflict, economic decline, increasing urban poor, increasing inequality, and macro-economic shocks. Climate change provides an additional threat that adds to, interacts with, and can reinforce these existing risks, placing additional strains on the livelihoods and coping strategies of the poor.(World Bank, 2002).

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. 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.*" This means that the assessment of vulnerability must be made at the appropriate spatial scale in order for it to be useful for defining the appropriate adaptation responses (Sullivan et al., 2006). Because the concept of vulnerability includes both the social, cultural and economic aspects discussed above, and the physical impacts that will be brought about by climate change, an approach which combines these different components is needed. Such impacts include changing environments, floods, droughts, tidal waves, and incidence of disease vectors. There are two key issues when considering these challenges. One is the radically different approaches in the disciplines that are relevant, broadly the socio-economic and the bio-physical sciences (each of which itself includes a multitude of different disciplines). The second is the very different spatial and time scales on which these two broad components normally operate, from the grid box hundreds of kilometres across of the global climate modellers, to the community scales of much analysis of human coping and adaptation potential. This means that climate behaviour needs to be characterised at spatial scales smaller than those of the current climate model output, and it needs to include more accurate estimations of rainfall (in addition to temperature), and of extreme events. Huge advances are being made in climate modelling, with improved representation of processes, and work is starting to be done at finer scales (regional climate models with grids typically of about 50 km), but this still remains very different to the community scale. It should be noted that the socio-economic aspects also include a range of other, overlapping scales – district, provincial, national and international inter-connections – that can all bear on people's vulnerability. A key problem, however, remains that of reconciling these very different spatial scales. In order to combine the disciplines and tackle these scale issues, we have developed the Climate Vulnerability Index (CVI), an index-based approach that draws together data from the bio-physical, economic and social sciences, and combines them in order to make a holistic assessment of vulnerability. The CVI does not consider all aspects of vulnerability, but it focuses on water, since water is a key component of all life and an essential element in all people's livelihoods. As such, it provides a very wide-ranging application of the approach, and includes many key aspects of vulnerability in general. This approach also makes the problem more manageable by not trying to consider all possible aspects at once. Further work could extend the CVI approach to examine other aspects, for instance, disease incidence related to climate change, or to apply the approach in locations where data is scarce..

The CVI has been introduced elsewhere and demonstrated at a preliminary level for both the community and national scales (Sullivan et al., 2002; Sullivan and Meigh, 2005). However, for wide application neither of these scales offers the best solution. National level assessments ignore the variations within countries, which are often very significant. For instance, the high mountains and plateaux in western China and the low-land coastal areas of the same country, are both expected to be at risk. In the mountains, these risks arise from glacial melting and increased flood and landslide risks on steep slopes, while coastal areas are under threat from loss of land due to sea level rise, and increased storminess. Clearly, these different factors need to be distinguished. Some degree of variation is found in almost all countries, even much smaller ones. At the other end of the spectrum, the huge number of separate locations means that the community scale is too fine for rapid assessments to be made over large areas. A recent report from the United Nations Development Programme (UNDP) on disaster reduction in relation to development supports the development of such indices, recommending that there is a need to "*support national and sub-regional risk indexing to enable the production of information for national decision makers*" (UNDP, 2004).

The objective of this paper is to show how an intermediate scale of application – a scale between the national and community levels – could be the way forward, leading to an approach which is practical for application over wide areas, but which still retains some of the spatial variation that is needed to define the different aspects of vulnerability in a way that would be useful for policy. This means that the results would be helpful in leading to actions to adapt to climate change where it is most needed. In other words, the key question we are examining is: How can the impacts of global change – both climate and other changes – be assessed at the spatial scale that matters, so that we can understand the impacts on people, and so that the appropriate policies can be developed?

The assessment of vulnerability at the appropriate spatial scale is seen as key step in developing adaptation responses that are effective, and can be focused on both development issues, and the needs of the poor. These issues are examined through a case study in Peru in which all the social and economic data are drawn from easily available sources, and the climate change data from existing climate models. Although the data used are not always ideal, the study shows that the CVI approach is practicable, and considerable progress can be made even with limited data availability. The potential for the extension of the approach in more comprehensive studies is also considered.

2. DEMONSTRATING GLOBAL VULNERABILITIES USING CLIMATE VULNERABILITY INDEX (CVI)

The *Climate Vulnerability Index* (CVI) provides a measurement of values which represent an assessment of human vulnerability to the impacts of global change on water resources (including bio-physical and socio-political drivers). High values of the CVI (which ranges from 1 – 100)[2] indicate a greater risk of being vulnerable to changing global conditions. The map in Figure 1 shows a global distribution of preliminary CVI values, providing insight into where human communities may be most impacted by climate and global change.

The *Global Impact Factors* (GIFs) which make up the main components of the CVI are: *geospatial variability (G), resource quantification (R), accessibility and property rights (A), utilisation and economic efficiency (U), capacity of people and institutions (C), and ecological integrity maintenance (E).* By combining these within a composite index, we obtain a measure which reflects the essence of what it means to be vulnerable, in the context of globalisation. This structure was first introduced as a tool for water resource assessment in the development of the Water Poverty Index (Sullivan, 2002). It is important to note that when any index is calculated, the importance of any of its sub-components may inherently be determined by how many sub-components there are in each of the main ones. Further, that importance can be adjusted by applying factors to these measures, which act as 'weights' to reflect the relative importance of each sub-component being measured. The relative importance of the components which underpin these *GIFs* in any country/location must be determined by the inhabitants, rather than by scientists who have set up the general framework, so that it can more accurately represent local conditions/values. These stakeholder-determined weights are added into the CVI calculation formula, so that communities who use the tool to assist with environmental management can easily input their own values to represent these weights. This way, the CVI presents a flexible tool for use in differing conditions[3].

For the purpose of calculating the CVI in this demonstration application at a variety of scales, we have decided to keep these multiplicative weights neutral by assigning them all an equal value of one[4]. In reality, we would hope that these weights would reflect the *degree of risk* associated with the impact of each of the components in question, measured on a probabilistic scale. We use the term '*r*' (shown in Eq. 1) to reflect, and remind users, that this *weighting value* should represent *the perceived degree of risk* associated with each component. In Eq. (1), X_i refers to component *i* of the CVI structure (i.e. the GIFs), for the site-specific location being considered, while *r* acts as a weighting, and represents risks associated with that particular GIF. Although the approach to the determination of the value of the GIFs is standardised across locations, the way this *r* value is calculated will be determined by the level of sophistication of the national science base of each location, and its monitoring and statistical capacity.

[2] Calculation of the Climate Vulnerability Index is made on a fully normalised set of indicators to reduce uncertainty associated with incommensurability.
[3] When comparisons are being made between different places, it is important to use the same variables with the same weights.
[4] Anyone thinking of using indices must familiarise themselves with the issue of weightings and their application. Such discussion is included in the scientific publications associated with this work

$$CVI = \frac{\sum_{i=1}^{N} r^i X_i}{\sum_{i=1}^{N} r_i}$$

For the purposes of comparison, as in our example here, our GIF indicator values are based on internationally accepted measures sourced from available data sources[5], with neutral weights being used to represent this risk factor. This provides a baseline global assessment, from which more refined local evaluations can be made through site-specific adaptation of the approach, with inputs on weights provided by the community of users and stakeholders. When this approach is applied using national level data, a value for each country can be calculated, as shown in Figure 1. The value of each of these national measures is generated on the basis of a combined set of sub-indicators which measure specific characteristics of each of the *GIF* identified above. By normalising all data on a scale between 1 and 100, it is possible to combine them, even though they represent widely diverging information, such as measurement of mean annual rainfall, per capita GDP, or child mortality rates. The Global Impact Factor '*Resource,'* for example, would ideally be based on a measure of how much of the resource (in this case, water) is available, what its quality is, and how variable is it in terms of meteorological fluctuations. In practice, for the purpose of international comparison, it is very hard to get a globally comparable measure for water quality, and so in some places data is not available for this sub-component. By using the FAO measure of '*total renewable resources'* (FAO, 2004), combined with a measure of rainfall variability, we have generated the resource measure used here. It is clear, however, that in any context, a national measure can only provide a general guide to conditions within a country, but for policy application, a more downscaled, site-specific approach would increase the *reliability*[6] of the assessment tool.

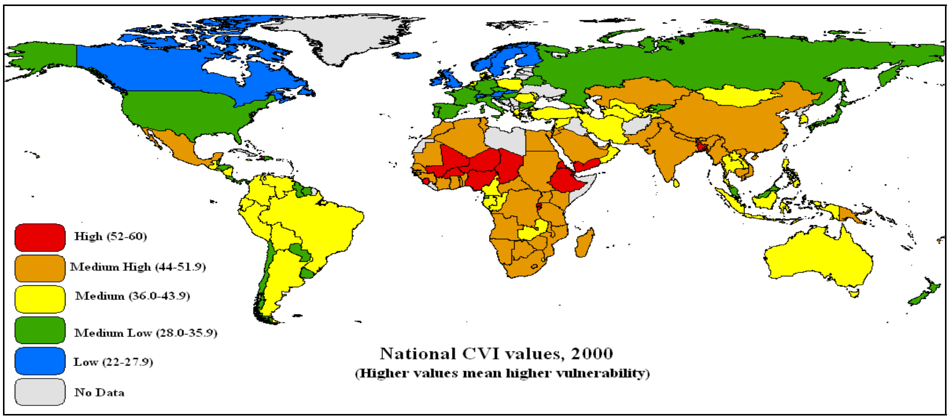

Figure 1. CVI scores can be used to depict a representation of how people are currently impacted by a combination of factors which reflect global change (Sullivan et al., 2009).

A preliminary presentation of this work was included in the 2nd *World Water Development Report* (UNESCO 2006), and the tool was identified in the Ministerial conference at the 2006 World Water Forum, by the Head of UNISDR, as being the kind of tool that is needed to address the important global risks we are now facing. Such a statement indicates a clear interest in this type of research, and future work on the CVI would take this further, by incorporating more explicit information both on water quality, and environmental flow requirements, both of which have now become more available since the CVI was first computed.

In order to examine how these GIFs influence us in the future, we follow a scenarios-based approach (Parry, 2004). In this example, we have used the '*Policy First*' scenario from UNEP (UNEP, 2002). This means we can apply reasonable assumptions about what may happen and how it will impact on us, to each of the GIFs, given that, according to the scenario, we follow globally agreed policy, as it is currently represented through international agreements (e.g. the MDGs). Each GIF is thus modified in terms of socio-economic conditions or climate change[7]. Figure 2 shows three examples of how the CVI can be applied to examine potential future change. Clearly, it can be seen that the degree of change in each GIF will be different, with some being much more affected than others, by various future changes. It is

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[5] These would include international organisations including UN Agencies, The World Bank and World Resources Institute, and internationally recognised NGOs.

[6] *Reliability* in the sense of meaning that it does what it is supposed to do, that is to provide a comparative evaluation on a multiscale framework, with a view to providing effective policy guidance.

[7] Climate change is estimated on the basis of outputs from the HadCM3, a coupled atmosphere-ocean GCM developed at the Hadley Centre, UK, and described by Gordon et al. (1999). The atmospheric component of the model has 19 levels with a horizontal resolution of 2.5 degrees of latitude by 3.75 degrees of longitude, which produces a global grid of 96 x 73 grid cells. This is equivalent to a surface resolution of about 417 km x 278 km at the Equator, reducing to 295 km x 278 km at 45 degrees of latitude

also possible to see that Bolivia is currently in a medium-risk situation, and it will continue to be in this category in the future, albeit with a slightly higher score. Big improvements can be achieved in terms of accessibility and property rights, and human and institutional capacity, but higher risk will be associated with resource availability, utilisation and economic efficiency, geospatial variability and the maintenance of ecological integrity, all of which will be threatened by changing global circumstances. In the case of Barbados, while it is only in a medium/low risk state at present, in the future this risk increases to a medium state, mostly due to increased vulnerability of resource availability, and geospatial factors (eg sea level rise). In Bangladesh, there is already a medium/high risk situation, and in the future this expected to worsen, into the high risk category, mostly due to increased geospatial risk and a reduction in environmental integrity.

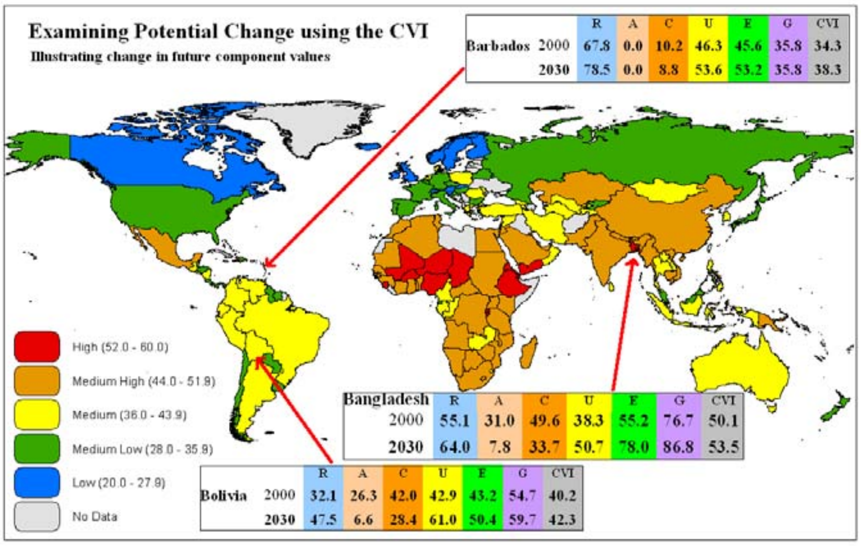


Figure 2. Considering the future – applying scenarios to component values.

In addition to mapping, further interpretation of the results of the CVI analysis can be seen by displaying the different *Global Impact Factors* on a multi-axis graph, allowing simultaneous comparison on these GIFs for the different places being examined. This is shown in Figure 3, which illustrates the average values for a group of countries in various risk categories, on each GIF. This type of representation enables strengths and weaknesses in each type of location to be examined. A higher score on any axis indicates the degree to which that particular *Global Impact Factor* is likely to be a source of vulnerability. It appears from this analysis that those countries in the high risk category (red) are likely to have problems associated with property rights and access, relatively lower and less reliable resource assets, and a lower degree of human and institutional capacity, with a higher geospatial risk.

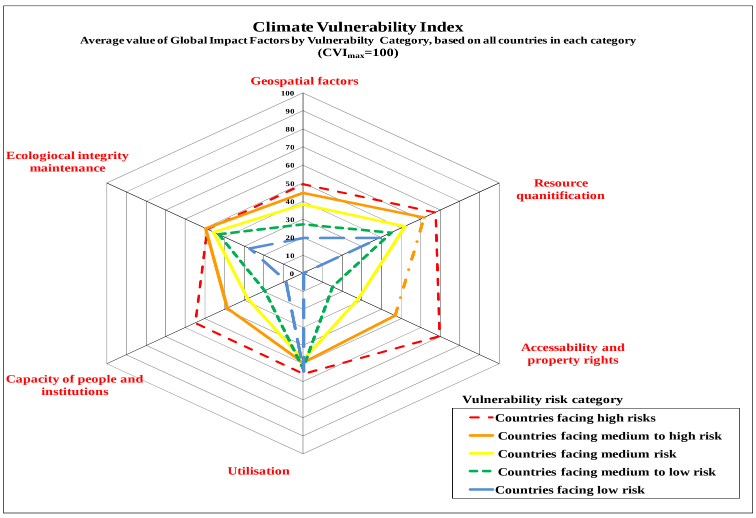


Figure 3. Main Global Impact Factors giving rise to vulnerability risk.

3. BEYOND THE NATIONAL SCALE

In order to examine those most at risk from the impact of climate and global change, it is important to look beyond national assessments. This is important for two reasons:

- A national representation does not provide any indication of how the risk is distributed across a country, either geographically, or on the basis of socio-economic variability within the country; and
- Vulnerability assessment may need to consider issues beyond the national scale. This could be within the context of the promotion of Integrated Water Resource Management, or in terms of regional demographic variability. For example, while many nations in one region may appear to have a high degree of vulnerability (e.g. Africa), it may be that another region may have more people who are at risk, due to their higher populations (e.g. Asia).

To look at these regional comparisons, and identify the number of people who may be at risk, we have identified two groups of countries to represent two continents. These differences are highlighted in Table 1. Where countries are omitted, this is due to lack of data.

Countries representing East and South Asia: Cambodia, India, China, Nepal, Vietnam, Myanmar, Pakistan, Bhutan, Papua New Guinea, Mauritius, Sri Lanka, Philippines, Mongolia, Singapore, Laos, Indonesia, Korea (Rep.), Thailand, Japan, Malaysia.
Countries representing Africa: Ethiopia, Niger, Eritrea, Chad, Nigeria, Djibouti, Rwanda, Mali, Burundi, Burkina Faso, Sierra Leone, Benin, Malawi, Guinea-Bissau, Senegal, Mauritania, Gambia, Mozambique, Morocco, Ghana, Lesotho, Angola, Sudan, Algeria, Uganda, Kenya, Egypt, Central African Rep., Togo, Botswana, Namibia, Tunisia, Congo DR(ex-Zaire), South Africa, Guinea, Zimbabwe, Zambia, Cameroon, Swaziland, Gabon, Congo (Rep).

When comparisons are made on this basis, we can see that overall, the number of people at risk in Africa is much less than those at risk in Asia, although some 240 million of Africans are highly vulnerable, while no country in Asia was included in that category. In addition to those at high risk, there are a further 430 million Africans at medium to high risk, although for Asia, the number of persons in that category is a massive 2,617 million. It is notable that no country in Africa falls into the medium to low, or low risk category.

	AFRICAN VULNERABILTY		ASIAN VULNERABILITY	
	Total, millions	% of continent	total , millions	% of continent
High Vulnerability	239.35	34.3	-	-
Medium -High vulnerability	429.37	61.5	2,616.4	82.0
Medium vulnerability	29.32	4.2	426.8	13.4
Medium - low vulnerability	-	-	149.0	4.7
Countries included	Ethiopia, Niger, Eritrea, Chad, Nigeria, Djibouti, Rwanda, Mali, Burundi, Burkina Faso, Sierra Leone, Benin, Malawi, Guinea-Bissau, Senegal, Mauritania, Gambia, Mozambique, Morocco, Ghana, Lesotho, Angola, Sudan, Algeria, Uganda, Kenya, Egypt, Central African Rep., Togo, Botswana, Namibia, Tunisia, Congo DR(ex-Zaire), South Africa, Guinea, Zimbabwe, Zambia, Cameroon, Swaziland, Gabon, Congo (Rep)		Cambodia, India, China, Nepal, Vietnam, Myanmar, Pakistan, Bhutan, Papua New Guinea, Mauritius,Sri Lanka, Philippines, Mongolia, Singapore, Laos, Indonesia, Korea (Rep.), Thailand, Japan, Malaysia	

Table 1. Comparing vulnerability in regions using the CVI
Note: These estimates are based on population figures for 2002

4. EXAMINING VULNERABILITY AT THE SUB-NATIONAL SCALE

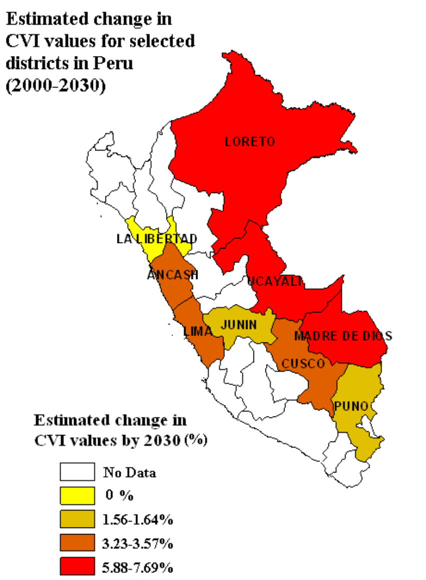
By using data from the sub-national scale (e.g. district or province), it is possible to refine the CVI assessment so that results can provide an insight into where specifically risks may be felt, within a country. This is much more valuable for policy-making, and is illustrated here for Peru. Table 2 shows the potential level of change to be expected across the country, by 2030. This suggests that most at risk are the areas of the Peruvian Amazon where a multitude of factors are impacting, both on people in the region, and on the ecosystem itself. This indeed is creating a cyclical problem in that increased deforestation at high altitudes is contributing to CO_2 emissions, which in turn further drives potential meteorological change.

5. CONCLUSIONS

There is no doubt that hundreds of millions of people are currently at a relatively high degree of risk from the impact of global changes of all types. This number is likely to increase in the future, not only because of the increasing risk of climate impacts, but also due to the large uncertainties associated with the socio-political dimensions of global impacts, and expected demographic change. It is important when we consider the impacts of climate change that we do so in recognition of the fact that any climate change will be happening simultaneously with other global changes. Given the huge number of people who are highly vulnerable in Asia, there is an obvious cause for concern in that continent. However, Africa is also an important focus, given that there is relatively little internal capacity to address these problems, whereas in Asia, while numbers are greater, the degree of vulnerability is somewhat less, and there is greater capacity internally to support efforts towards adaptation. Nevertheless, across the world it is highly likely that those persons who will be most impacted by climate and other forms of global change are likely to be those who are currently most vulnerable, and so it will be important for development agencies to address the key issues of poverty reduction and population control, within their climate adaptation programmes. When we look at the factors which impact most severely on the countries with the greatest potential risk of global and climate impact, we can see that these are likely to have problems associated with property rights and access, relatively lower and less reliable resource assets, and a lower degree of human and institutional capacity, with a higher geospatial risk. Information such as this can help organisations to prioritise their attention to different pressures which arise in different places, giving rise to vulnerability to climate and other forms of global change.

Table 2. Subnational analysis in Peru reveals internal diversity of vulnerability risk

Change in CVI values



Source: Sullivan, Huntingford and O'Regan (2009)

Summary of component and CVI values, districts in Peru

Department	Year	Component Values: Geo-spatial variability	Resource quantification	Accessibility. property rts	Capacity of people and institutions	Utilisation and economic eff	Ecological integrity	CVI
Coastal zone								
Lima	1993	50	66	72	54	58	64	61
	2030	58	65	65	34	62	94	63
Ancash	1993	55	65	74	50	39	56	57
	2030	63	67	68	35	42	74	58
La Libertad	1993	65	67	70	44	41	58	58
	2030	78	53	62	37	44	77	59
Mountain zone								
Junin	1993	77.5	65	81	50	46	48	61
	2030	91	64	77	32	46	63	62
Cusco	1993	77.5	64	85	56	42	50	62
	2030	91	65	81	41	42	64	64
Puno	1993	77.5	89	80	59	42	39	64
	2030	91	89	75	43	42	51	65
Amazonian zone								
Loreto	1993	15	15	88	62	16	9	34
	2030	18	28	85	46	28	13	36
Ucayali	1993	31	31	89	62	14	9	39
	2030	39	43	86	45	27	14	42
Madre de Dios	1993	17.5	17	79	53	18	19	34
	2030	21	31	74	36	31	24	36

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