The Climate Vulnerability Index (CVI) and an illustration of its application to Mongolia

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Water is the primary medium through which climate change influences Earth's ecosystem and thus the livelihood and well-being of societies" (WWAP, 2012).

1. Introduction

The Earth's climate and its hydrological cycle are intimately connected. The ***Climate Vulnerability Index* (CVI)** (Sullivan and Meigh, 2005; Sullivan and Huntingford, 2009) is a holistic and interdisciplinary tool developed to provide a clearer understanding of how climate and other global impacts on water resources are likely to influence human populations. While this analysis does not try and structure the analysis based on the DPSIR[3] indicator framework, it does recognise that there are certain drivers and pressures which do give rise to various states, and it is in response to these states that this ***Climate Vulnerability Index*** does aim to provide guidance as to what may be appropriate policy responses. This is useful for governments to assist in resource prioritisation.

Based on a participatory multicriteria framework, the CVI is a composite index designed as a simple-to-use tool which can be derived largely from existing data. It requires the calculation of a baseline score which takes account of a wide range of relevant factors, clustered within 6 core components, referred to as *Global Impact Factors (GIFs)*. These are:

- *Geospatial variability,*
- *Resource quantification,*
- *Accessibility and property rights,*
- *Utilisation and economic efficiency,*
- *Capacity of people and institutions, and*
- *Ecological integrity maintenance.*

After the baseline for current conditions is assessed, scenarios of global change are applied to evaluate potential future conditions. This approach provides the means by which the distribution of water-related climate impacts on people can be mapped, both for the present, and for the future. This means that decisions can be made not only on past information, but also on informed expectations of future changes[4]. The result of this is that resources can be directed to those areas where adaptation measures are most needed, and most likely to have the greatest impact.

2. Why this tool is relevant in Mongolia: Local evidence of a changing climate

Mongolia is characterised by extreme cold in winter, yet can be hot in summer. While there have been a number of years where unusually cold conditions have occurred (1946/7, 1968/9, and 1984/5), the overall trend over the last 70 years has been one of general warming, as shown in Figure 1.

Many rivers in Mongolia are fed by snow melt, but rising global temperatures are changing ice cover quite dramatically. For example, in Tsambagarav Mountains, the size of the snowcap reduced by 13.4% between 1940 and 1992, and by 2000 this reduction reached 28.8%. By 2002, the icecap had decreased in size by 31.9% in compared with the 1940s (Davaa et al., 2005), as shown in Figure 2.

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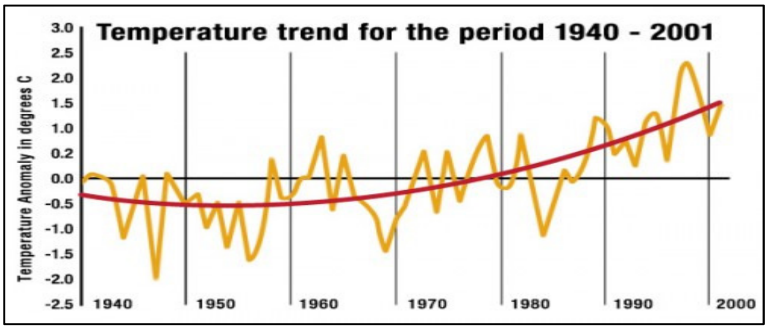
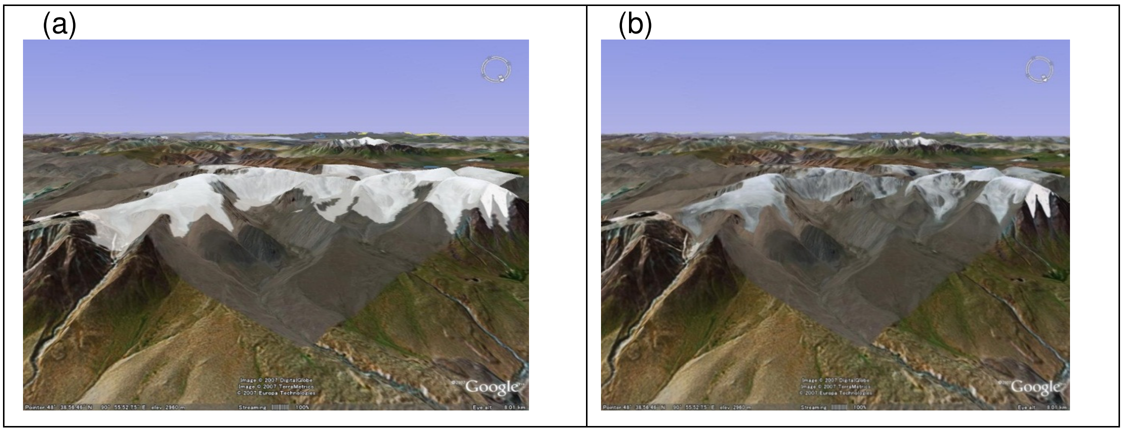
[3] The DPSIR framework (**D**rivers, **P**ressures, **S**tates, **I**ndicators, and **R**esponse) has been widely used as a means to understand processes of change and how these may be identified through the use of indicators.
[4] It must be acknowledged that as in all evaluations of water resources, uncertainty exists in both current data and future expectations, but this can be addressed by examining the range of possible results

Figure 1 Temperature trends in Mongolia, 1940 – 2001



Source: Batima et al., 2005

Figure 2 Change in glacier extent, Tsambagarav Mountains 1940 (a) to 2007 (b)



Source: (Davaa et al., 2005)

As a result of these changing conditions, observations have indicated that many lakes and rivers in Mongolia are receiving less input from glaciers, while higher temperatures are increasing evaporation rates, causing river levels to decrease. In arid areas, groundwater levels are dropping causing desertification to spread northward. According to the surface water inventory of Mongolia conducted in 2007, some 16% of rivers in the country have dried up, with over 25% of springs and almost 30% of lakes suffering the same fate. These changes in the hydrological regime are having significant effects on the quantity and quality of the nation's water resources (Dagdavorj et al.,2009).

3. Water resources in Mongolia

Mongolia is situated in the central part of the Asiatic continent, and is one of the driest countries of the world, characterised by arid and semi-arid zones. Annual precipitation in Mongolia varies between 250-400 mm per year, with more than 60% occurring during summer months. Most precipitation falls in the north of the country, decreasing to the south where the Gobi desert receives only about 50 mm per year (Batima and Dagvadorj, 2000).

In any area, estimations of total water availability are extremely difficult to calculate. They are based on available time series data of surface water, with groundwater estimates being taken into account if relevant, as in the case of Mongolia. In 1999, total freshwater resources were estimated to be about 599 cubic km per year. Of this, 83.7% is contained in lakes, 10.5% held within glaciers, and only 5.8% of the total surface water resources flow in rivers and streams (Myagmarjav and Davaa, 1999, cited in Davaa et al., 2007). Renewable ground water has been estimated at 10.8 cubic km per year (Jadambaa, 2002 cited Davaa et al., 2007). According to the Water Census data (2007) from Ministry of Nature, Environment and Tourism, total water resources per capita was 523,645.7 cubic metres.

4. How water is used in Mongolia

As in all countries, use is determined not only on the basis of hydrological conditions, but also on economic, political and even social conditions.

Table 1 Total water use in Mongolia

Sectors		Water use, M^3 million
Domestic/municipal		71.50
Agriculture:	Livestock	71.00
	Irrigation	52.28
Industry:	Manufacturing	35.80
	Mining	93.80
	Power station cooling	27.60
	Hydropower	80.00
Tourism		1.68
Green area/conservation		0.27
Total water use		433.93

Source: Myagmarjav and Davaa 1999 cited Davaa et al., 2007

5. Calculating the Climate Vulnerability Index

Once appropriate variables have been identified for the specific place in question, and data assembled, the current CVI values can be determined using a multicritera framework. The multiple components are assembled under six core themes designed to capture the *key drivers of human vulnerability to climate related impacts on water resources*. The structure of the CVI is a weighted average of multiple components, written mathematically as:

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

where *G, R*, *A*, *C*, *U* and *E* are the *Geospatial variability, Resource quantification, Accessibility and property rights, Capacity of people and institutions, Utilisation and economic efficiency* and *Ecological integrity maintenance*. Here, the weight given for each component is determined by a factor *r* representing the relevance of the component in a specific place, and the likely degree of risk associated with it. Data used in this analysis of Mongolia are shown in Table 2.

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 higher values indicating high vulnerability. By applying scenarios of future conditions, the change in the CVI scores from the present values indicate how different CVI *Global Impact Factors* will impact on the selected aspects of human lives (Sullivan and Huntingford, 2009).

Table 2 Indicators used to represent *Global Impact Factors* for the CVI value for Mongolia

Global Impact Factors (GIFs)	**Data used for each indicator**	**Source data**
Geospatial variability (G)	• Isolation from the capital city (food sources) • Human population density • Range in altitude (slope)	• Dist from capital, Mong Rd Atlas 2004 • Statistical yearbook 2008 • Topog Map NASA SRTM 90m DEM data
Resource quantification (R)	• Ave annual precip (mm) * • Total water res per capita (M^3) *	• Statistical yearbook 2008 • Water census 2007, MNET /HDR, 2011
Accessibility and property rights (A)	• Useable water resource per capita (cubic metre) * • Domestic water use (litre per day) *	• Water census 2007, MNET cited in Mongolia HDR, 2011 • Stats yearbook 2008, Basandorj (2011)
Capacity of people and institutions (C)	• Under 5 mortality rate (per 1000 live births) • Tot sch children as % of school age cohort * • GDP per capita (1000 togrogs) *	• The MDGs Implementation, 2009 • National Statistical office, 2008 • Statistical yearbook 2008
Utilisation and econ efficiency (U)	• Econ return on ag water use (togrog) * • Econ return on ind water use (togrog) * • Econ return on mun water use (togrog) *	• Statistical yearbook 2008 • Statistical yearbook 2008 • Statistical yearbook 2008
Ecological integrity maintenance (E)	• Forest area (hectare) * • Pasture-damaged land (in percentages) • Livestock density • Road network (km)	• FAO (2007),Darkhan gov • MNET, 09 Mong HDR, 2011 • National Stats office, 2008 • Mongolian Road Atlas, 2004

Note: Indicators marked with * must be inverted to reflect negative impacts. For example, high rainfall will reduce water vulnerability by increasing water resources and availability, but the high livestock density will increase vulnerability. This means the score for rainfall must be inverted to reflect its impact on the overall CVI score, since high CVI means high vulnerability.

Source: Byambaa, 2012

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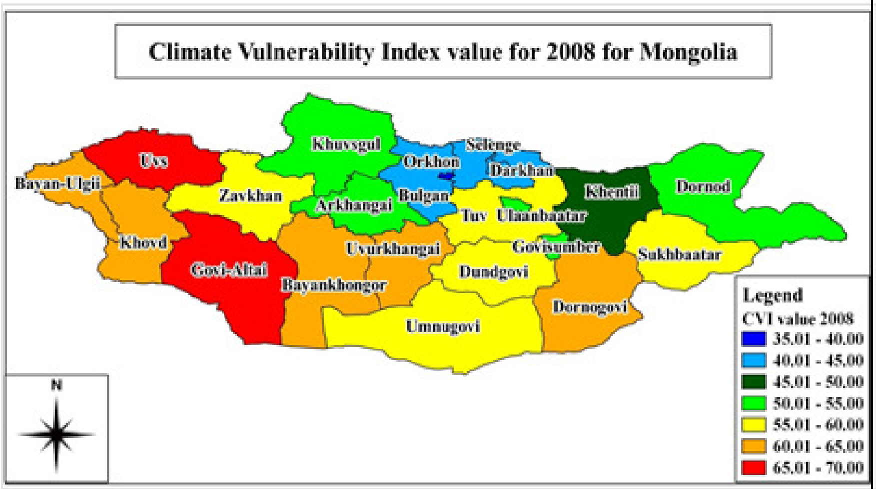
Table 3 Climate vulnerability index values for selected provinces of Mongolia (high values indicate higher levels of vulnerability)

Provinces	Geospatial variability	Resources quantification	Accessibility and property rights	Capacity of people and institutions	Utilisation and economic efficiency	Ecological integrity maintenance	Climate Vulnerability Index value
Selenge	17.24	49.54	40.53	44.75	76.54	24.91	**42.25**
Khentil	25.17	20.92	45.82	65.88	67.59	45.07	**45.08**
Ulaanbaatar	40.68	70.76	85.92	59.16	19.52	45.48	**53.58**
Domogovi	11.60	99.09	74.08	79.05	60.59	48.37	**62.13**
Uvs	56.81	88.23	87.22	41.22	62.24	55.33	**65.18**

From this study it is clear that human vulnerability to climate induced impacts on water resources is currently variable across the country, as shown in Figure 3.

Figure 3 Variability in CVI scores, Mongolia, 2008

These mapped values of the CVI show that the most vulnerable areas currently are the west and south of the country, while the North and East is less vulnerable. Most vulnerable provinces in 2008 are Uvs and Govi-Altai, while the least vulnerable are Orkhon, and Selenge.

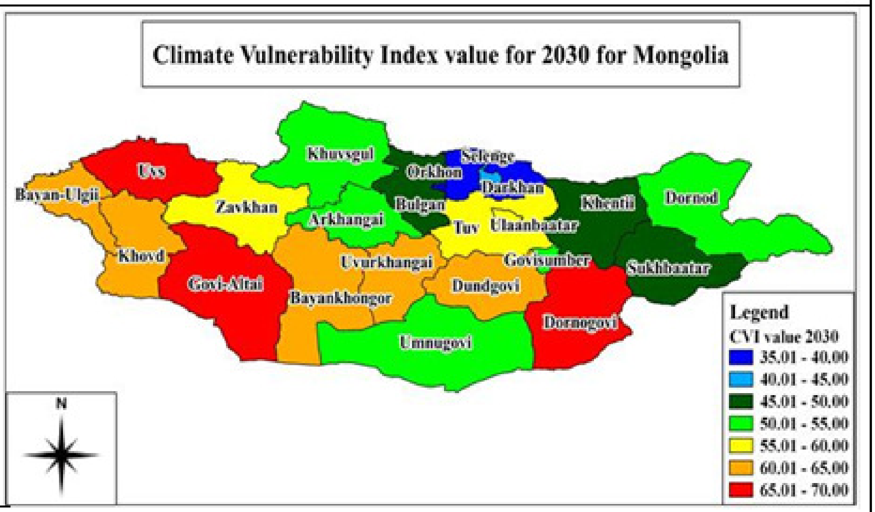


Assessing the CVI for 2030

To consider how conditions may change in the future, it is necessary to apply scenarios of change to all the baseline (2008) component values. This includes application of accepted findings form climate models for the region on water resources, as well as considering population change and economic growth. Details of how this is done are listed in Appendix A, and results shown in Fig, 4.

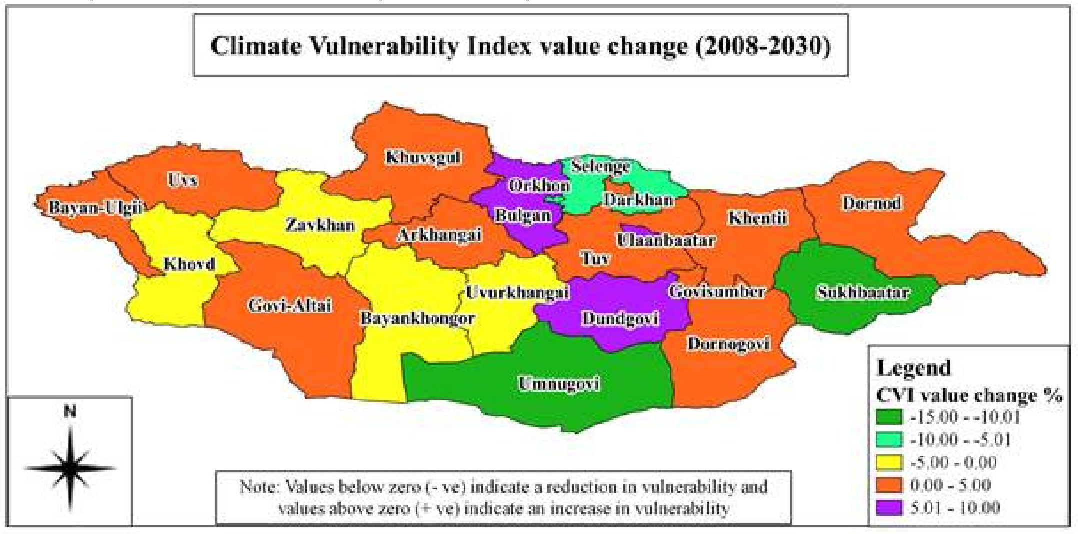
Figure 4. Projected CVI values for Mongolian Provinces for 2030

The CVI values for 2030 show how many provinces of Mongolia will become more vulnerable in the future, although conditions in some will improve. Eg. Ulaanbaatar and Bulgan become more vulnerable, and Umnugovi and Sukhbaatar are likely to become less vulnerable.



The changes between the two periods can be mapped for clarity, as shown in Figure 5.

Figure 5 Changes in the CVI show where places are becoming more vulnerable (+ve values), or less vulnerable (-ve values)



This map shows that the regions which are becoming more vulnerable to changes in water resources are likely to be Dundgovi, Bulgan and Ulaanbaatar, while Sukhbaatar and Umnugovi are likely to be less vulnerable than at present. The main reasons for the changes in this period are due to changes in *Capacity of people and institutions* and *Utilisation and economic efficiency*.

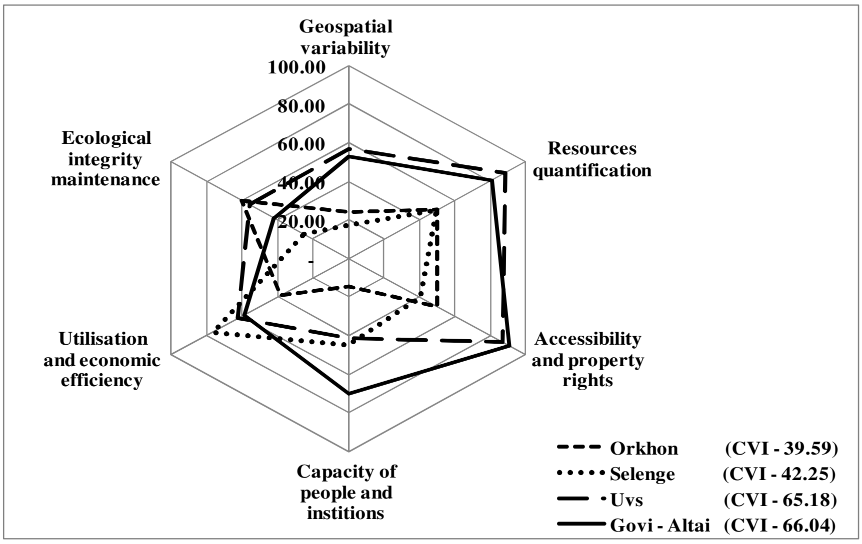
Discussion

There are a number of issues to be considered when using the CVI.

1. *Moving away from single numbers*

Many people criticise indices for collapsing information into single numbers, but in the CVI this is avoided by presenting the *vulnerability profiles* for the locations in question, as shown in Figure 6. This allows the values of individual components to be examined, especially for the purposes of comparison over time or between locations.

Figure 6 Comparing CVI values of four provinces of Mongolia



2. *Data issues*

As with the use of data in all types of assessment, data used here is subject to errors and uncertainty, both of definition and measurement. If a country wishes to apply such a tool in evaluating its future prospects, much effort should be put into verifying and improving the quality and resolution of its national data. Similarly, if data or values are used from international sources, or from climate models, efforts should be made to examine the range of possible scores and take this into account when CVI calculations are made.

3. *Weighting of components*

One of the most contentious issues in the use of composite indices concerns the weightings used in the final calculation. In the example provided here, weightings are kept neutral, as we believe that weightings represent societal values, and should be determined by stakeholders and elected representatives, rather than by scientists.

4. *Issues not included*

In any analysis it is necessary to establish the frame of reference for the work, and the boundary conditions. To this end, we note that there has been no attempt here to include vulnerability to flooding or other extreme events, as that is beyond the scope of this work.

Conclusion

This paper has provided some insights into how the CVI can be used to evaluate human vulnerability to the impacts of global change on water resources. Although the focus is on climate change, it is recognised that climate change will happen at the same time other global changes are also happening, such as population growth and economic development. The method presented is to be seen as an iterative one, with much potential for further application and improvement. Nevertheless, there is much scope for its use in understanding more about why and how human populations are likely to become more vulnerable in the future, and given the urgency of the need for adaptation in the face of global change, the use of the CVI provides a useful tool for resource prioritisation.

Acknowledgements

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