A NEW APPROACH TO THE ASSESSMENT OF VULNERABILITY TO DROUGHT

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J. Alcamo[1], L. Acosta-Michlik[2], A. Carius[3], F. Eierdanz[1] R. Klein[2], D. Krömker[1], D. Tänzler[3]
[1] *Center for Environmental Systems Research, University of Kassel,* [2] *Potsdam Institute for Climate Impact Research,*
[3] *Adelphi Research, Berlin*

Summary

This study aims to improve the estimation of vulnerability to drought by analysing and comparing differences between three distinct disciplinary perspectives (economics, political science, and behavioral science/environmental psychology). To make this comparison we developed a new methodology for quantifying susceptibility which consisted of (i) translating qualitative knowledge into inference models, (ii) converting qualitative model variables into quantitative indicators by using fuzzy set theory, (iii) collecting data on the values of the indicators from case study regions, (iv) inputing the regional data to the models and computing quantitative values for susceptibility. The methodology was successfully applied to three case study regions having a range of socio-economic and water stress conditions -- Andhra Pradesh, India; Algarve and Alentejo, Portugal; Volgograd and Saratov, Russia. In some cases the estimates of susceptibility were surprisingly similar, in others not, depending on the factors included in the disciplinary models and their relative weights. For example, both the psychology and economics perspectives compute the susceptibility of the Russian and Portuguese regions to be about the same, but because of different factors. The methodology provides a consistent basis for comparing differences between perspectives, and for identifying the importance of the differences.

1. Aim of the Research

The main objective of this project is to improve the estimation of vulnerability of society to droughts through a better understanding of the differences between disciplinary viewpoints. It is thought that a better understanding of these differences will lead to a synthesis of important insights from the different disciplines. The focus of the project is on vulnerability of the population of a region to drought. To better compare disciplinary views we divide the vulnerability concept into three component parts[1] (i) the "susceptibility" of society (i.e. the converse of adaptive capacity), which is a function of attributes of society such as it preparedness for disasters, (ii) "water stress" which is a reflection of nature's pressure on society, and (iii) drought-related societal "crises". This is the division used in the analytical tool called "security diagrams" (Alcamo, 2001; Alcamo and Endejan, 2001). The approach of the project is to quantify and compare these concepts in a standardized way using data from three contrasting case study regions – Andhra Pradesh, India; Algarve and Alentejo, Portugal; Volgograd and Saratov, Russia. These regions cover a wide range of socio-economic and water stress conditions.

In this paper we first describe the methodology developed for modeling and quantifying susceptibility. Next we use this methodology to compare susceptibility from three different disciplinary perspectives. We then describe the development of a crisis data set for testing estimates of vulnerability. Finally, we use the crisis data to test the validity of various water stress indicators and their thresholds.

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[1] Working definitions of *susceptibility, water stress and crisis* as used in this project are adapted from Alcamo (2001). They are all given in the context of environment and security. (1) *Susceptibility* -- the capability of an individual, community, or state to resist and/or recover from crises brought about by environmental stress. (2) *Transient environmental stress* (of which *water stress* is taken as a sub-category) -- the intensity of an environmental change that (i) involves an undesirable departure from long-term or "normal" conditions, (ii) is of short duration (iii), is directly or indirectly influenced by society, and not only the result of natural geologic factors (as in the case of volcanoes and most earthquakes). *(3) Crisis* -- an unstable or crucial time or state of affairs brought about by environmental stress in which a decisive and undesirable change is impending or occurring, and which requires extraordinary emergency measures to counteract.

Box 1. Methodology for quantifying susceptibility

1. Developing inference models – The first step is to translate qualitative knowledge into verbal statements. This could be knowledge from a social science theory or construct, or observation. Usually the statements are in the form of assertions, as in “If public expenditures on health care are high, then susceptibility tends to be low.” The different verbal statements are then related together in statements such as “If public expenditures on health care are high, and if expenditures on infrastructure are high, then susceptibility is low”. Measurable (or at least estimatable) indicators are selected for each element of the statements. For example, the percentage of GDP spent on public expenditures for education and health is used as an indicator of “public expenditures”, while the percentage of total cropland devoted to irrigation was used as a proxy variable for “infrastructure”. Data on these indicators are collected from the case study regions. We developed separate inference models for behavioral science/ psychology, economics, and political science.

2. Quantifying the models with fuzzy set theory – Fuzzy set theory is then used to convert expert opinion about “high”, “low” and “medium” in the inference model into numerical values. Fuzzy set theory is also used to weight one set of factors versus another so that a final quantitative value for susceptibility can be estimated.

3. Collecting data – The values of indicators in the inference model are then measured or estimated in the case study region. “Top-down” statistical data are used for the economics and political science models, and “bottom-up” survey data for the environmental psychology model.

4. Computing susceptibility – Data collected in the previous step are input to the models and a quantitative value for susceptibility is computed.

2. Principal Results

2.1 New Methodology for Quantifying Susceptibility from Different Disciplinary Perspectives

A central objective of this project is to elaborate and compare the concept of susceptibility from three distinct disciplinary perspectives – economics, political science, and behavioral science/environmental psychology. For this task we develop a new methodology to quantify susceptibility (Box 1) and use it to derive three separate models of susceptibility, each representing a different disciplinary perspective (Box 2). This approach helps fill typical gaps in numerical data with local and expert knowledge. Moreover, it provides a consistent basis for comparing differences between perspectives and for identifying the importance of differences.

2.2 Comparison of Susceptibility from Regions and Perspectives

Figure 1 presents estimates of susceptibility for the case study regions. This is one of the first attempts to compare quantitative estimates of susceptibility to drought from three different disciplinary perspectives. An interesting result was that the three perspectives computed similar quantitative estimates for the susceptibility of the Portuguese region (0.17 to 0.35). This could indicate that the methodology is insensitive to the question of susceptibility in Portugal or that a wide range of disciplinary perspectives give a similar susceptibility rating for richer countries. This must be tested by applying the approach to a variety of industrialized regions. The psychology and economics models also estimated that the Russian and Portuguese regions have about the same susceptibility, although we had expected that the Russian region would be more susceptible because of the difficult socio-economic transition it is undergoing. The psychology model estimates a relatively low susceptibility in Russia despite this transition because individuals and communities have a relatively high level of resourcefulness in the face of droughts and other crises. This more than compensates for factors that tend to increase susceptibility. In the economics model the Russian region received relatively high scores for education and gender equity, and the model assumes that these tend to produce a low susceptibility. The political model, however, computes a much higher susceptibility for the Russian region because of the high level of

Box 2. Disciplinary models of susceptibility

Susceptibility model from environmental psychology perspective

The model of susceptibility from the psychological perspective is based on the concept of “agents” and their subjective assessment of a threatening situation. (Agents are groups of individuals such as households.) This assessment determines the agents’ actions and hence their susceptibility. This modeling approach is consistent with recommendations that the “internal side” of vulnerability should be considered (Bohle, 2001; Chambers, 1989; Kasperson & Kasperson, 2001). The model is based on protection-motivation-theory (Rogers, 1983; Rippetoe and Rogers, 1987) successfully applied in the risk-health area (Milne, 2000). Following from this theory, susceptibility can be defined as the lack of protection capacity of agents. If agents think the situation is threatening but they believe they can cope with it then this theory suggests that protection capacity is high, and subsequently, susceptibility is low.

Susceptibility model from socio-economic perspective

The model of susceptibility from the socio-economic perspective is based on the idea that susceptibility is related to the inability of the state and free market to provide sufficient economic and social resources to society for coping with water stress. The model is related to the concept of “double exposure” (O'Brien and Leichenko 2000) which suggests that regions characterised by economic marginalization and high-risk environments may be potential “double losers”. The specific relationships depicted in the model are derived from the economic development theories of “modernization” and “dependency”.

Susceptibility model from political science perspective

The model of susceptibility from the political science perspective focuses on the concept of state capacity. For assessing this capacity we can draw on different approaches to measuring government performance (e.g. Arbetman and Kugler 1997). In addition, other cultural resources such as traditional knowledge can sometimes compensate for inadequate state capacity (Berkes, 1999). Hence social and economic factors should also be taken into account. To integrate these aspects into a model, we use a systematic approach based on the theory of Parson (1971). In a nutshell, this approach identifies the dimensions of a society crucial to its general functioning and thus to its stability The interplay of political, economic, social and cultural dimensions provides the necessary environment for society to carry out its desired functions such as goal attainment, adaptation, integration and pattern maintenance. In this light, susceptibility means insufficient state capacity to guarantee these desired functions, which in turn means that a certain degree of (environmental) stress will lead to a crisis situation. This approach implies that an inference model of susceptibility from the political perspective must include information on the political, economic, and socio-cultural dimensions of a society.

“conflict involvement” and "degree of corruption" which are assumed to contribute to susceptibility.

All three disciplinary perspectives assign Andhra Pradesh in India the highest susceptibility of the three case study regions, although absolute values ranged from 0.58 to 0.79. The lowest value was estimated by the economics perspective, partly because it assumed that the region’s dependence on irrigated agriculture serves as a hedge against drought. Of course having large agricultural areas dependent on irrigation can also be viewed as a large exposure to drought.

How can knowledge from the three perspectives be integrated into a comprehensive model of susceptibility? The psychological perspective suggests that we should include indicators that capture the ability of individuals and communities to be creative and resourceful in mitigating the impacts of droughts. From the political perspective, we are reminded that political stability is an important factor to include in a general susceptibility model. From the economics perspective we learn that access to infrastructure and gender equity may play important roles in overall susceptibility.

2.3 Using “Crisis Data” to Validate Vulnerability Estimates

Although scientists have invested a large effort in estimating vulnerability to drought and other climate events, this effort has been hampered by an inability to validate these estimates. When is the level of susceptibility or water stress high enough to cause concern? In this project we have experimented with using the occurrence of “drought-related crises” as an independent variable for testing vulnerability estimates. The concept of drought-related crises as we use it here implies that water stress is high enough to have negative impacts on society. We have compiled crisis data through a media analysis using key words to identify the

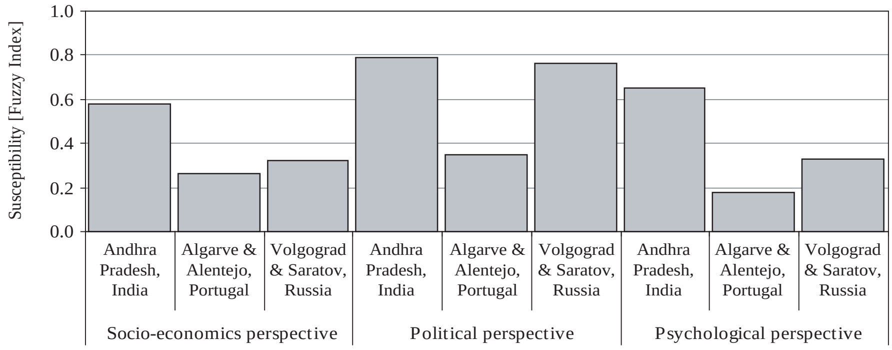

Figure 1. Comparison of susceptibility computed from different disciplinary perspectives.

occurrence of crises. Our source of information is the Factiva data base which summarizes key words for over 8000 local and regional media sources around the world dating back to 1980. We sum up this information in Table 1 which shows the years in which we estimate that drought-related crisis occurred in the case study regions. Table 1 provides an independent basis for testing water stress as described in the next section.

2.4 Testing and Identifying Thresholds of Water Stress With Crisis Data

Water stress is an oftern used concept for assessing the impacts of water scarcity on society. Several indicators have been used to measure water stress, but their use and thresholds have been supported mostly by expert judgment rather than scientific evidence. Therefore it is particularly interesting to use the crisis data set described above as an opportunity to independently test different water stress indicators. Table 2 shows the indicators having a statistically significant relationship to the occurrence of drought-related crises (t-test with 0.95 significance level). The highest statistical relationship with water stress is achieved by a new indicator "MaxIndex" (see Table 2) which is a combination of three other indicators (Figure 2). These results are preliminary because they are based on a small data, and because they rely on the somewhat subjective concept of drought-related crises. Nevertheless, considering the diversity of regions that are covered by these results, this seems to be a promising approach for testing water stress indicators and identifying their thresholds

Table 1. Drought-induced crisis events in the case study regions 1980 to 1995 based on findings of media analysis.

19...	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
India					X		X	X						X		
Portugal		X		X									X	X		X
Russia					X		X		X							X

Table 2. Results of t-tests for the occurrence of crises and different water stress indicators.

Statistically significant indicators	**Not statistically significant indicators**
▪ Water withdrawal to availability ratio	▪ Water withdrawal to internal availability ratio
▪ Deviation of groundwater recharge from long time average	▪ Annual groundwater recharge in mm
▪ Deviation of water availability from long time average	▪ Groundwater discharge per capita
▪ Runoff deficit index	▪ Water availability per capita
▪ Deviation of evapotranspiration from long time average	▪ Internal renewable water availability per capita
▪ MaxIndex (maximum of water withdrawal to availability ratio, deviation of water availability from long term average, and percentage of area with high water stress (defined as water withdrawal to availability ratio of 0.4 or higher).	▪ Percentage of area under stress (defined as withdrawal to availability ratio of 0.4 or more)
	▪ Percentage of population under stress (population in areas under stress defined as withdrawal to availability ratio of 0.4 or more)
	▪ Deviation of precipitation from long time average

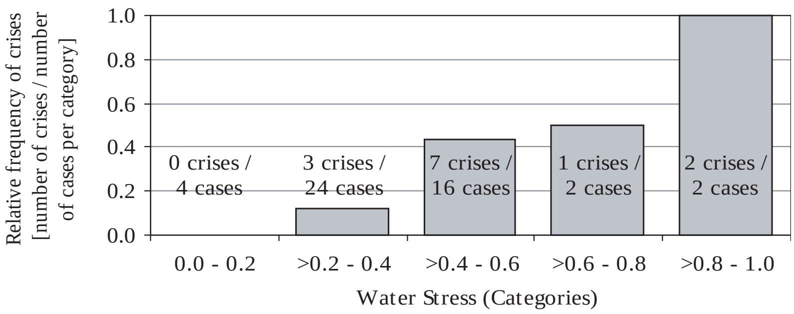

Figure 2. Relationship between MaxIndex indicator of water stress and relative frequency of crisis events.

3. Main Conclusions and Policy Relevance

In this study we elaborate a new methodology for quantifying susceptibility to drought. The methodology is flexible and easy to implement and has potentially wide applications outside of this study. It can be used to identify not only the comparative susceptibility of a population to drought, but also the major factors leading to its susceptibility. This information can provide concrete input to policies for increasing the adaptive capacity of a population. Furthermore, the methodology provides an effective way to include not only expert knowledge but also local knowledge in a vulnerability assessment. Hence it provides a method to involve and actively engage stakeholders in vulnerability assessments

The application of this methodology showed how different disciplinary viewpoints can be successfully represented and compared with inference models. As such it provides a first step towards synthesizing insights from different perspectives into a comprehensive concept of vulnerability to drought..

References

Alcamo, J. 2001. Environment, security and the question of quantification. *International Journal of Sustainable Development*. **4**(2). 139 - 156.

Alcamo, J. and Endejan, M. 2001. The security diagram: An approach to quantifying global environmental security, in Petzold-Bradley, *et. al*. (eds). Responding to Environmental Conflicts: Implications for Theory and Practice. NATO ASI Series. Kluwer: Dordrecht. 133-147.

Arbetman, Marina and Jacek Kugler (eds.) 1997: Political Capacity and Economic Behavior. Boulder (Colorado): Westview Press.

Berkes, Fikret 1999. Sacred Ecology. Traditional Ecological Knowledge and Resource Management. Taylor & Francis, Philadelphia and London.

Bohle, H.-G. (2001). Vulnerability and Criticality . Perspectives from social geography. IHDP update, 2, 3-5.

Chambers, R. (1989). Vulnerability, Coping and Policy. IDS Bulletin 20, p. 1-7.

Kasperson, J. X., & Kasperson, R. E. (2001). International Workshop on Vulnerability and Global Environmental Change (1). Stockholm: SEI Risk and Vulnerability Programme.

Milne, S., Sheeran, P. & Orbell, S. (2000). Prediction and intervention in health-related behavior: a meta-analytic review of protection motivation theory. Journal of Applied Social Psychology, 30(1), 106-143.

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

Parsons, Talcott 1971: The System of Modern Societies. New Jersey: Prentice-Hall.

Rippetoe, A. P., & Rogers, R. W. (1987). Effects of Components of Protection-Motivation Theory on Adaptive and Maladaptive Coping With a Health Threat. Journal of Personality and Social Psychology, 52(3), 596-604.

Rogers, R., W. (1983). Cognitive and Physical Processes in Fear Appeals and Attitude Change: A Revised Theory of Protection Motivation. In J. Cacioppo & R. Petty (Eds.), Social Psychophysiology (pp. 153-176). New York: Guilford Press