PNNL-18136

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
Under Contract DE-AC05-76RL01830

Climate Change Vulnerability and Resilience: Current Status and Trends for Mexico

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December 2008

Pacific Northwest
NATIONAL LABORATORY

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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Abstract

Climate change alters different localities on the planet in different ways. The impact on each region depends mainly on the degree of vulnerability that natural ecosystems and human-made infrastructure have to changes in climate and extreme meteorological events, as well as on the coping and adaptation capacity towards new environmental conditions. This study assesses the current resilience of Mexico and Mexican states to such changes, as well as how this resilience will look in the future.

In recent studies (Moss et al. 2000, Brenkert and Malone 2005, Malone and Brenket 2008, Ibarrarán et al. 2007), the Vulnerability-Resilience Indicators Model (VRIM) is used to integrate a set of proxy variables that determine the resilience of a region to climate change. Resilience, or the ability of a region to respond to climate variations and natural events that result from climate change, is given by its adaptation and coping capacity and its sensitivity. On the one hand, the sensitivity of a region to climate change is assessed, emphasizing its infrastructure, food security, water resources, and the health of the population and regional ecosystems. On the other hand, coping and adaptation capacity is based on the availability of human resources, economic capacity and environmental capacity.

This paper presents two sets of results. First we show the application of the VRIM to determine state-level resilience for Mexico, building the baseline that reflects the current status. The second part of the paper makes projections of resilience under socioeconomic and climate change and examines the varying sources and consequences of those changes. We used three tools to examine Mexico's resilience in the face of climate change, i.e., the baseline calculations regarding resilience indices made by the VRIM, the projected short-term rates of socioeconomic change from the Boyd-Ibarrarán computable general equilibrium model, and rates of the IPCC-SRES scenario projections from the integrated assessment MiniCAM model. This allows us to have available change rates for VRIM variables through the end of the 21st century.

Keywords: Climate change, Mexico, Model Projections, Adaptive Capacity, Resilience, Vulnerability

Contents

1.0 Introduction

In the past few years and especially since the publication of the Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report in 2007, attention has shifted from the question, "Is climate change real?" to the questions, "How severe will the changes be?" and "How can societies both mitigate change and build adaptive capacity?" These shifts in attention bring into focus rich veins of scientific research on the vulnerabilities of specific places, the potential for climate-related disasters and disaster responses, and strategies to prepare for climate change impacts. What these research foci have in common is that they are centered in analysis of human welfare rather than the physics or chemistry of the climate. They consequently open up the realm of decision-making beyond recommendations on the technical feasibility of various policy options—to a consideration of overall societal development in the context of economic, political, and cultural conditions.

Studies of societal vulnerabilities, resilience, and adaptive capacity have both added to the knowledge base and provided new tools for such analyses. Much of the existing literature on these topics is in the forms of case studies of particular societies and sectoral studies, notably in agriculture. Although these are extremely valuable in the particular contexts of their research objects, the IPCC has, since its Second Assessment Report, identified two important challenges in its impact assessments (Watson et al. 1996, 1998, McCarthy et al. 2001): to improve approaches for comparing and aggregating impacts across diverse sectors and populations and to model socioeconomic transformations as well as climate change in assessing the future significance of climate change.

Inevitably, comparative studies sacrifice the valuable details of case studies in favor of a necessarily sparse set of data that is available for all the units of analysis. This allows the 10,000-meter view of places that can be compared and begins to map out the variability of both vulnerability and resilience—but such an analysis cannot replace a closer look at specific aspects that must be the basis for decision making.

Moreover, quantification and modeling are desirable but subject to the same issues that confront energy-economic integrated assessment (IA) models: the dependence on several levels of assumptions, possible lack of important variables, co-linearity, lack of accounting for interactions/feedbacks, and so on (Parson and Fisher-Vanden 1997).

Nevertheless, vulnerability and resilience assessments point the way to an integrated model that can provide potential insights and guidance in the areas of impacts, adaptation, and societal behavior. The model used for this study, the Vulnerability and Resilience Indicators Model (VRIM) is a nascent approach to meeting this objective.

This paper connects the likely impacts of climate change and Mexico's resilience to it—that is, the extent to which Mexico and its states have the capability to maintain the livelihoods and well-being of their citizens as they are exposed to warmer temperatures, more and more severe climate events (especially droughts), and sea level rise. We first discuss our emphasis on resilience (rather than on vulnerability) and the advantages of doing so, then outline the methodology for our comparative analysis of resilience at the country and state levels. We describe our model and the indicators used to comparatively assess resilience at the country and state levels. The model results show differences in levels and sources of resilience; two-state comparisons provide further insight about differences among states, suggesting differentiating strategies will be important in building resilience.

2.0 Vulnerability Studies of Mexico

When impacts research began to expand beyond estimates of damages to agriculture, coastal areas, and the like, the initial focus was on vulnerability. In the case of Mexico, there has been a vast amount of research addressing vulnerability, mainly from a biophysical and sociological point of view.

Blaikie et al. (1996) propose a new approach to vulnerability that takes into account the social, economic and political environment of disasters. The analytical model, the Pressure and Release (PAR) model, examines the evolution of unsafe conditions, specifically dynamic pressures such as urbanization and environmental degradation, and the origin of their causes and background explained by the political economy. This model incorporates the temporal dimension, the disruption not just of the lives and property but also of livelihoods, and the difficulty of rebuilding again in the future. Against the physicalist vision that disasters are caused directly by events or physical threats, Blaikie et al. claim that a disaster occurs when unsafe conditions in the social system converge with a natural hazard, i.e., when a considerable number of people experience a hazard and suffer serious damage and/or disruption of their subsistence system, such that recovery is unlikely without outside help.

Several studies examine vulnerability within this framework. For example, Florescano (1980) states that “the most disastrous effects of drought, as in the earlier times, are concentrated in the rain-fed agriculture practiced by the poorest ejidatarios and campesinos, lacking credit, irrigation, fertilizers, and improved seeds.”

On the other hand, Liverman (1990, 1994) defines natural hazard vulnerability “as the characteristics of places or people that are likely to be harmed by meteorological and geophysical events” and adds that “Mexico has become more vulnerable to drought in recent years” because of the expansion of commercial agriculture and land reform, which create groups of poor rural dwellers with limited and insecure access to land resources. Throughout her analysis, she focuses mostly on drought and mentions pregnant women, children, elderly, the poor, and the ones who live in areas of high hazard as the most vulnerable to natural disaster. She also states that technology does not always reduce biophysical vulnerability. Irrigation, variety of improved seeds, and fertilizers can reduce vulnerability, but technology also replaces traditional hazard prevention strategies such as mixed cropping and expands agriculture into areas of high hazard risk such as mountains, coastal regions, and disease-susceptible humid tropics. This often translates into dependency on foreign imports and further environmental degradation. So landlessness, poor soils, and political weakness, mixed with inappropriate technologies, make some people more vulnerable to drought than others. The conditions and variables are divided into six groups: environment, technology, social relations, demographics and health, land use and ownership, and economy and institutions.

Eakin et al. (2007) look at social vulnerability of farmers in Mexico (and in Argentina), and find that their main source of vulnerability is the trend toward large, single-product farm units. In addition, in the case of Mexico, the lack of income diversification and access to financial and material resources increases their sensitivity and lowers their adaptation capacity, since they do not have a buffer against climatic risk.

García Acosta (coord.) (2005) argues that there is a social construction of a disaster, caused basically by poverty, exclusion, the lack of urban planning and corruption. Preexisting vulnerability conditions cause risk, and natural phenomena increase these vulnerabilities to extremes when disasters occur.

Vera (2005) adopts the definition posed by Blakie et al. (1996) that social vulnerability is defined as the capacity to have access to resources, both to cover basic needs as well as to allow for decision making and economic and political participation. To understand vulnerability, risk, and disaster, the study should look at multiple causes, including the existence of cacicazgos (or individuals with strong local economic power and leadership), land concentration, land degradation (due to deforestation and erosion) and an unequal distribution of resources among regions, where low productivity regions receive less than those with high productivity. In addition, regions may lack services related to health, water, energy and education, with a predominantly rural population experiencing malnutrition, profound poverty and income distribution issues, migration to new touristic complexes and abandonment of their land, and disparities in the sharing of assistance due to political fragmentation. However, Vera foresees that the affected populations may learn from their experience and mitigate their vulnerability. Thus, disasters may be an opportunity for change.

Villegas (2005) perceives disaster as a social process resulting from the extreme expression of two produced and reproduced social conditions: risk and vulnerability. She therefore analyzes the social conditions under which vulnerability is produced, following Hewitt (1993), who argues that disasters are the impact of extreme geophysical events on a passive population.

More in the line of urban vulnerability, Satterthwaite et al. (2007) understand vulnerability to climate change as the potential of people to be killed, injured or otherwise harmed by the direct or indirect impacts of climate change. Particularly, urban vulnerability is seen as the result of weak governments and poverty, a more frequent situation in low-and middle-income nations where people have limited resources and infrastructure to resist an event caused by climate change. The researchers mention several studies of urban vulnerability, where Mexico is included in the broader case of Latin America and the Caribbean.

García Avila (2007) defines vulnerability as the process by which human population and ecosystems are subject to damage or threat due to social and biophysical factors. Water itself can be one factor of vulnerability. She looks at 11 types of water-related vulnerabilities, making an assessment of the status of 13 different hydrologic regions of Mexico (according to the National Comission of Water (Comisión Nacional del Agua, CNA)).

Sánchez (2008) looks at how the effects of human behavior and interaction, consumption, land use and land cover change, climate change, and population growth increases vulnerability in an area. He argues that "the biggest challenge for a broader global environmental change perspective on cities is the creation of new conceptual frameworks and methodologies to study these issues" (Sánchez, 2002). He also addresses sustainability, decentralization, and public policies as factors to reduce vulnerability in urban areas, and discusses the consequences to an area that does not consider these components.

3.0 Current Focus on Resilience

As in most of the studies discussed above, vulnerability is often connected with research on natural disasters. Climate change, while it may encompass more severe weather-related disasters, has other impacts of a more gradual nature. In this way, the concept of vulnerability offers only a narrow lens of analysis. Moreover, vulnerability is a deficit concept; researchers and analysts are examining what is wrong, with at least an implicit conclusion that these vulnerability-contributing factors need correction. Such an approach contains sign problems for those who might use the research to help improve conditions for affected people and to design adaptation activities. Using vulnerability studies, decision-makers must keep in mind that, while high values of many attributes are good (high income, test scores), high vulnerability is actually bad, so instead of trying to raise low values, the recommendations have the effect of suggesting that decision-makers work on lowering high scores.

To address these concerns about vulnerability, we focus on the concept of resilience. Resilience has a robust history in ecology, beginning with Holling (1973); Folke (2006) describes the evolution of the term in ecology and in social-ecological systems analysis. The term's meaning has evolved over time. Originally, resilience most often meant a return to a previous state. A perturbation hit a system and (quickly or gradually) it went back to its original condition. Subsequent work, both on ecosystems and societies, has identified the potential for multiple equilibria and the possibility of successfully adapting to changed circumstances by developing a new state. Thus, resilience includes both an element of recovery and an element of change. Moreover, it is a positive concept; high "scores" are good and factors like air pollution and lack of education are negatives. This makes intuitive sense as the results of an assessment are discussed.

And, resilience is not simply the inverse of vulnerability, as the IPCC definitions show (Parry et al. 2008, 880 and 882):

> **Resilience**: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.
>
> **Vulnerability** is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability of extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

The VRIM, like the definition of resilience, focuses on adaptive capacity, balanced by the sensitivity of human and ecological systems, without including a climate change term (except to exposure to storm surges), as the definition of vulnerability does.

4.0 Modeling Baseline Resilience for Mexico and Mexican States

To evaluate the extent and sources of Mexican resilience to climate variability and change, we use a comparative, quantitative framework, the VRIM. The VRIM was developed specifically to integrate socioeconomic and environmental information and provide this quantitative comparative basis for assessing resilience.

Even though, as discussed above, there is a vast amount of qualitative work in Mexico (and abroad) on vulnerability, there is a definite need to measure the relative resilience among places. This is the objective of this paper. There are many international efforts to compute such indexes, as described below (Moss et al., 2000; Brenket and Malone 2005, Brooks et al. 2005, Cutter et al. 2003, and Pratschke y Haase (2000), to name a few). However, this has not been done for Mexico.

An index may be computed using any of several methodologies. Here we present three alternatives used in the literature. One uses factor analysis approach, another expert judgment and econometrics, and a third econometrics.

Cutter et al. (2003) create an index of social vulnerability to environmental hazards for the United States at the county level, using 1990 data. They define vulnerability as the potential loss due to social and place inequality. In this paper they analyze social vulnerability (and leave out place-specific vulnerability). Their methodology consists in the use of an un-weighted additive model where variables are selected through principal components. Variables are then normalized, scaled and added to compute a summary score. (For other examples of the use of Principal Components Analysis, see Townsend et al. (1988), Carstairs and Morris (1990), and Coombes et al. (1994)).

Brooks et al. (2005), on the other hand, use expert judgment to select a broad range of indicators that explain vulnerability and capacity to adapt to climate change at the national level and on a decadal timescale. Even though national level data makes strong simplifications, it produces valuable information used at the central government level. They define as their outcome variable vulnerability to mortality that results from population exposed to natural hazards through the proportion of the population that died due to climate variability-caused disasters (and by extension to climate change), with respect to total population, and look at what the determinants of this ratio are. Using expert groups, they make a list of over 40 indicators and then through correlation analysis determine 11 key variables at the national level to include into a vulnerability index. Again using expert judgment, they assign weights to the variables used for the index and obtained an average score to produce a composite vulnerability index. Finally, they perform a sensitivity analysis by changing these weights.

In a third type of analysis, in a study of Mexico's Yaqui Valley, Luers et al. (2003) posit a generic vulnerability metric that measures a threshold of damage against the susceptibility of a system's sensitivity to and exposure to stressors. Their threshold metric is the wheat yield of a farm.

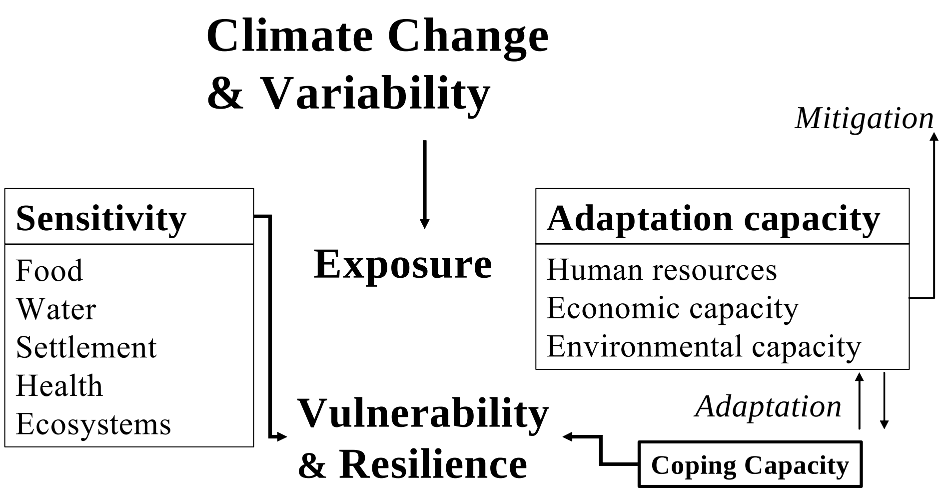
The VRIM in our analysis of Mexican states is more downscaled in that it analyzes states instead of nations, as opposed to Brooks et al. (2005), but is more aggregated than Cutter et al. (2003) that looks at counties. The selection of variables is based on a wide-ranging literature review and includes variables that can be measured, even though other more qualitative aspects are being explicitly left out due to measurement issues or to a lack of a clear variable to represent specific concepts, such as in the case of social capital, for instance.

Although very useful for quantifying the vulnerability of specific variables, the Luers et al. (2003) methodology does not yield the sort of integrated assessment we seek. Moreover, the VRIM-based state-by-state comparisons more closely mimic the processes of policymakers who must make tradeoffs among issues that can and cannot be addressed.

4.1 Model Description

The VRIM is a hierarchical model that aggregates a number of proxy values into sectors, which in turn are aggregated into sensitivity and adaptive capacity values, and finally into a vulnerability-resilience index. The first two levels of the structure are shown in Figure 1.

Figure 1. A simplified diagram of the Vulnerability-Resilience Indicators Model (VRIM)



The third level comprises 1-3 proxy variables under each sector; all 18 proxy variables, by sector, are listed in Table 1 (see also Brenkert and Malone 2005), along with a description of what the proxy stands for and how it functions in the model. When sensitivity of the proxy is high (↑) resilience will be low (↓); similarly, when capacity to respond is high (↑) resilience will be high (↑). For projections, (↑) implies an assumption of increasing and (↓) implies an assumption of decreasing resilience. If specific exposure events, such as a drought or hurricane, occur, resilience will decrease (either an interruption in an increasing variable or a further dip in a decreasing variable). The last column of Table I is discussed in section 5.

Exposure, that is, the nature and extent of changes that a place's climate is subjected to with regard to variables such as temperature, precipitation, and extreme weather events, is implicitly incorporated. The impact of potential sea level rise is explicitly simulated. The impact of exposure will depend on the development of socioeconomic and environmental capital and is determined by forward-looking adaptation and/or by setbacks from negative impacts from hazards and climate change and variability.

Table 1. Structure and relationships in the VRIM (including bases of projections)

	Sector	Indicators / data	*Proxy for*	Functional relationships	Projected with
Sensitivity	Settlement/ infrastructure sensitivity	Population at flood risk from sea level rise	Potential extent of disruptions from sea level rise	• Sensitivity ↑ as population at risk ↑ • Resilience over time ↓ as population at risk increases over time and sea level rises	Population change from the SRES scenarios; sea level rise from MiniCAM output
		Population no access clean water/sanitation	Access of population to basic services to buffer against climate variability and change	• Sensitivity ↑ as population with no access ↑ • Resilience over time ↑ as GDP per capita increases over time	Indexed safe drinking water access and indexed safe sanitation access projected with GDP per capita changes
	Food security	Cereals production/ crop land area	Degree of modernization in the agriculture sector; access of farmers to inputs to buffer against climate variability and change	• Sensitivity ↓ as production ↑ • Resilience over time ↑ as production technology increases over time[1].	Crop yield changes from MiniCAM output
		Protein consumption/ capita	Access of a population to agricultural markets and other mechanisms (e.g., consumption shift) for compensating for shortfalls in production	• Sensitivity ↓ as consumption↑ • Resilience over time ↑ as protein consumption increases and the undernourishment index decreases	Indexed nutritional index = [2] $y = 45.711Ln(x) - 365.88$ $R^2 = 0.60$
	Ecosystem sensitivity	% Land irrigated	Degree of human intrusion into the natural landscape	• Sensitivity ↑ as % irrigated ↑ • Resilience - over time ↓ as % agricultural/irrigated land increases	Land use change from MiniCAM output
		Fertilizer use/ cropland area	Nitrogen/phosphorus loading of ecosystems and stresses from pollution	• Sensitivity is ↓ if use < 60 kg/ha or > 100 kg/ha; ↑ when use=>60 and <100 kg/ha • Resilience over time ↑ when fertilizer use increases up to 60 kg/ha but ↓ over time with levels > 160 kg/ha	Fertilizer use changes based on land use changes from MiniCAM output
	Human health sensitivity	Completed fertility	Composite of conditions that affect human health including nutrition, exposure to disease risks, and access to	• Sensitivity ↓ as fertility ↓ • Resilience over time ↑ as birthrates decrease to a sustainable level	Indexed birth rate = $y = 22.732Ln(x) - 162.32$ $R^2 = 0.34$

1 Erosion and desertification may result in the opposite direction which could be tested in a more fine-grained scenario analysis

2 Where x is GDP per capita

		Life expectancy	health services	• Sensitivity ↓ as life expectancy ↑ • Resilience - over time ↑ as (healthy) life expectancy goes up	Indexed life expectancy = y = 47.832Ln(x) - 393.01 $R^2 = 0.66$
	Water resource sensitivity	Renewable supply and inflow and water withdrawal	Ratio of water supply from renewable resources and withdrawals to meet current or projected needs	• Sensitivity ↑ as % water withdrawal ↑ • Resilience over time ↓ as % available fresh water demand increases	Water demand changes based on agricultural production from MiniCAM output
		Precipitation	Precipitation amount in mm	• Sensitivity ↑ as % irrigated land ↑ • Resilience over time ↓ as precipitation decreases (and ↑ with increasing precipitation)	unchanged
Coping & Adaptive Capacity	Economic capacity	GDP(market)/ capita	Distribution of access to markets, technology, and other resources useful for adaptation	• Coping / adaptive capacity ↑ as GDP per capita ↑ • Resilience over time ↑ as GDP per capita –increases	GDP and population changes from SRES scenarios
		Income equity measure	Realization of the potential contribution of all people	• Coping / adaptive capacity ↑ as poverty or inequity ↓ • Resilience - over time ↑ as poverty or inequity decreases or the human development index increases	Unchanged due to lack of data
	Human and civic resources	Dependency ratio	Social and economic resources available for adaptation after meeting other present needs	• Coping / adaptive capacity ↓ as dependency ↑ • Resilience over time ↓ as the % of people dependent on the working population increases	Indexed dependency ratio = y = 42.087Ln(x) - 349.31 $R^2 = 0.66$
		Literacy	Human capital and adaptability of labor force	• Coping / adaptive capacity ↑ as literacy ↑ • Resilience over time ↑ as literacy increases	Indexed literacy rate = y = 45.09Ln(x) - 359.56 $R^2 = 0.59$
	Environmental capacity	Population density	Population pressure and stresses on ecosystems	• Coping / adaptive capacity ↓ as population density ↑ • Resilience over time ↓ as population density increases	Population changes from SRES scenarios