Scale Counts:

A Review of Indicator-based Climate Change Vulnerability Assessments

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Executive Summary

Latin America and the Caribbean (LAC) region are extremely susceptible and exposed to the threats of future climate change as effects have already been noted with an average increase in temperature of about 1°C, changes in precipitation, and more frequent and intense extreme events (United Nations Environmental Programme (UNEP) et al. 2010). There is an urgent need to strengthen the national capacity of each country in the region to identify and implement adaptation strategies that are based on locally derived information and vulnerability assessments.

This report is based on a compilation of selected vulnerability cases studies that have been carried out globally, regionally and internationally with an emphasis on the water and agriculture sectors. These sectors were chosen since most countries in the region have identified these areas as being the most important to the socioeconomic conditions of their country, and also likely to be the most vulnerable to changes in climate (CATHALAC, 2008; Torre et al. 2009; UNEP et al. 2010).

Although several tools and methodologies are available to carry out vulnerability assessments including: qualitative diagnostics based on literature reviews and local documentation, future model simulations, statistical analysis or indicators-based approach, this review has been limited to those studies that have used the indicators-based approach. As such, the examples presented in this report should not be considered an exhaustive compilation of all vulnerability assessments carried out regionally or internationally.

Climate change vulnerability evaluations are critically needed in order to provide decision-makers with the information necessary to mainstream adaptation measures into policy and planning yet a lack of data, information and tools is a key constraint in realizing these assessments in the LAC region. This review identified 35 vulnerability case studies carried out across the globe at different scales using the indictors-based approach as the main tool of analysis. These studies show that vulnerability to climate change varies across the globe, between regions, within countries, watersheds and even among farmers in the same community practicing divergent agricultural activities. These early examples provide useful information on the strengths and weaknesses associated with the indicators and data used in these assessments and most importantly the significance of the scale of analysis.

Key Findings

Global Assessments

- Global level assessments are questioned for their utility for policy making as the findings provide very little detail on the causes and distribution of vulnerability in each country

- Global level assessments present conflicting and at times counter-intuitive results. In some instances developed countries are considered more vulnerable than countries in the LAC or African regions

- Global assessments not only overlook in-country variations but also tend to lump regions into one category of vulnerability

- Final results of who is vulnerable and who is not is highly dependent on the data and indicators used in the analysis, which have important implications if adaptation resources are distributed based on these findings

- Results from global level assessments appear to be very uncertain and should be taken with caution

Latin American and the Caribbean Assessments

- Studies show that vulnerability is spatially differentiated between countries, regions within the same country, populations sharing the same watershed and importantly even between types of farmers in the same community

- Vulnerability assessments at the ecosystem or farm scale are likely to share more commonalities in terms of their environmental and socio-economic vulnerabilities and therefore adaptation measures may also be shared. As such, there is a critical need to scale down the analysis to a more local community-based assessment or ecosystem-based approach, which may require moving beyond traditional political and administrative boundaries

- Data constraints and challenges building future climate and socio-economic scenarios has resulted in many studies maintaining a "business as usual" perspective and either 1) evaluating current socio-economic and environmental vulnerability to current climate threats or 2) evaluating current socio-economic and environmental vulnerability combined with future climate change projections.

- Indicators-based approach provides useful information when carried out at smaller scales and indicates the areas and populations at risk and does not require extensive data or technical and financial resources compared to more complex modeling simulations

Key Recommendations

- Global and national level assessments should only serve as a preliminary step in carrying out more detailed analysis at the ecosystem, watershed and/ or farm scale and should move beyond political and administrative boundaries

- Because of differences in data availability, indicators used, and climate threats faced by various countries comparing vulnerability assessments should be carried out critically and cautiously

- There are no pre-established sets of indicators that can be applied in each country across the region that will provide a clear and detailed analysis and allow for comparisons between countries. For each country to understand their unique vulnerabilities to climate change indicators should be selected based on the data availability in the country

- The indicators-based approach is recommended over modeling simulations since many countries in the region lack the data requirements and financial and technical resources to carry such assessments that often report similar findings

- Current social-economic conditions are a key factor in determining an populations' present and future vulnerability and maintaining this under future climate change scenarios is appropriate and reduces uncertainties in the assessment

- Constructing future socio-economic scenarios is fraught with challenges, uncertainties and subjectivity. Evaluating current social vulnerability and maintaining this under future climate change scenarios is appropriate and reduces uncertainties in the assessment

- The importance of the socio-economic conditions cannot be understated and is a key factor in determining a populations overall vulnerability. A recommended approach to evaluating vulnerability at the national scale is to undertake a multi-criteria assessment incorporating social, economic and environmental vulnerability variables and map the results using GIS. Information on future changes in precipitation and agriculture land area may then be overlaid identifying "hotspot" areas, which may then be targeted for more in-depth analysis.

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Acronyms

ACCII: Adaptation to Climate Change project
AIACC: Assessments of Impacts and Adaptations to Climate Change
CAMA: Centro de Agricultura y Medio Ambiente
CASEN: Encuesta de Caracterización Socioeconómica Nacional
CCCC: Caribbean Community Climate Change Centre
CONAGUA: Comision Nacional del Agua
CONAM: Consejo Nacional del Ambiente
CONAPO: Consejo Nacional de Población
CRI: Climate Risk Index
CVI: Climate Vulnerability Index
EVI: Environmental Vulnerability Index
IDEAM: Instituto de Hidrología, Meteorología y Estudio Ambientales
IMTA: Instituto Mexicano de Tecnología del Agua
INEGI: Instituto Nacional de Estadística y Geografía
IPCC: Intergovernmental Panel on Climate Change
LAC: Latin America and the Caribbean
MINAM: Ministerio del Ambiente del Perú
PVI: Prevalent Vulnerability Index
SIAP: Servicio de Informacion Agroalimentaria y Pesquera
UNDP: United Nations Development Programme
UNEP: United Nations Environmental Programmers
UNFCCC: United Nations Framework Convention on Climate Change

1.Vulnerability

A review of the vulnerability literature demonstrates that there are an extensive number of definitions for the concept yet the one that is commonly referred to in the climate change literature is provided by the Intergovernmental Panel on Climate Change ((IPCC) 2007):

> *Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is* ***exposed*[1]**, *its* ***sensitivity*[2]**, *and its* ***adaptive capacity*[3]**.

A second term that requires defining is resiliency, which the IPCC (2007) defines as:

> *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-organisation, and the capacity to adapt to stress and change.*

Both of these terms are critical to understanding not only the potential impacts from climate change but also how these impacts will vary across geographical space and among populations based on the local socio-economic and environmental conditions. A developed country and a developing country may be exposed to the same climate threat, yet the vulnerability of the developed country may be less due to their access to financial, technical and human resources. Consequently, vulnerability studies should include the physical impact from climate change on the sector or ecosystem of analysis and its adaptive capacity.

Climate Change in the LAC Region

The geographical, biophysical and socio-economic diversification of the LAC region means that the impacts of climate change will vary between countries and even within them. In general, the majority of the region is expected to experience an increase in temperature, which may be between 1°C-4°C under the B2[4] IPCC

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[1] Exposure: the nature and degree to which a system is exposed to significant climatic variations (IPCC, 2007).
[2] Sensitivity: the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC, 2007).
[3] Adaptive capacity: the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007).
[4] Scenario B2 includes some level of mitigation with more efficient use of energy and clean technology and improved localized solutions.

scenario or 2°C-6°C under the A2[5] scenario. Precipitation changes are much more complex to predict and are highly dependent on the climate scenario and model applied. For instance, two different model simulations carried out for Central America and the tropical regions of South America show conflicting results with either a reduction in precipitation from 20%-40% or an increase by 5%-10% for 2080 (UNEP et al. 2010).

The sector most likely to suffer from the impacts of changes in temperature and precipitation is agriculture, and with a few exceptions such as some areas in the southern cone that may experience an expansion in the suitability of crop cultivation, these impacts will have adverse effects across the region (Torre et al. 2009). The economic impacts on the agriculture sector may be quite severe as some studies suggest that land values decline as temperature rise. One study in South America shows that even after farmers implement adaptation measures they may still experience a loss of 12%-50% of their revenue due to climate change (Torre et al. 2009). The effects on rural poverty may be even more severe as a reduction in agricultural productivity in Brazil is estimated to increase rural poverty by 2%-3.2% (Torre et al. 2009). While the direct impacts from temperature and precipitation changes will affect agriculture productivity other indirect impacts may result from sea-level rise (lose of productive land, salt water intrusion), infestation of pests and disease and land and soil degradation.

The impacts of climate change on agriculture and water resources will vary between the LAC countries and even within them. Table 1 and 2 presents a summary of some of the expected implications of a change in climate as described in each country's National Communication report.

Table 1 Climate Change Impacts on Water Resources in the LAC

Country	Impact on Water Resources
Antigua and Barbados (2001)	Rising sea-level threatens the viability of fresh water aquifers. Water resources are currently stressed. Projected population growth coupled with variability in rainfall will likely exacerbate water stress in the country
Argentina (2008)	The observed and predicted changes in temperature and precipitation in the Plata Watershed may result in a reduction in hydro generation, its use as a transport channel and impacts on drinking water. In Cuyo hydrologic models suggest a reduction in river flows of up to 13% in the Mendoza River, and 29% in the San Juan River by 2020-2030. Reduction in flows in the Comahue and Patagonia are expected to reduce hydroelectric generation in the country, in the Colorado River a reduced flow will effect irrigation of crops in the region and the Chubut River may lose 20% of its flow by 2020-2040 limiting the potential to expand agriculture land under irrigation.
Bahamas (2001)	Current strain on water resources combined with sea-level rise pose a high risk to fresh water resources on the islands and therefore the ability to meet the demands

[5] Scenario A2 projects a less dynamic economy, less globalization and high population growth.

	from the population, tourism and agriculture.
Barbados (2001)	The aquifers are exposed to salt water intrusion and increase frequency and severity of drought may intensify the availability of fresh water resources. An analysis on future sea-level rise on the west coast shows that the well water may no longer be suitable for human consumption, inflicting 51, 000 people and the tourism industry
Belize (2002)	The quality of freshwater resources may be adversely affected by salt water intrusion. The city of Belize's drinking water supply is threatened from an increase in sea-level rise, which could cause salt water to penetrate the area upstream from where the water source is located. Hydroelectric generation is also threatened from increase temperatures and evaporation and reduced precipitation during the dry season.
Brazil (2010)	Water stress is expected to increase due to population growth and economic development combined with changes in the hydrologic cycle. Because of the multiple uses of the main watershed São Francisco conflicts regarding water usage may arise as supplies become strained. A similar situation may be expected in the Paraná River watershed as it is critically important to the country's electrical system but also serves the largest population density. A reduction in rainfall will also cause the Amazonian and the Cerrado forest biomes to lose their moisture becoming much more susceptible to fire and mortality.
Bolivia (2009)	The high plateau area may experience problems with power generation, increased water needs for irrigation, low water availability for human and animal consumption, a reduction in the recharge of the aquifers and competition for water uses. In the valley region competition for water use, increase water needs for irrigation and problems with power generation may be experienced. In Chaco, competition for water use and increased pollution of water resources is expected and finally in the Llanos and Amazonia outbreaks of infectious disease related to water borne illnesses may be experienced, and reduction in the glacier cover may affect the country's drinking water supply.
Chile (2000)	Temperature rise could increase river flows due to melting ice reserves, however in the long-term the central region may experience a decrease in run off due to reduced precipitation and the eventual loss of the glaciers.
Colombia (2010)	Reduction in precipitation is predicted to have a significant impact on freshwater resources especially in the departments of Bolivar, Magdalena, Cesar, Santander, Tolima and Amazonas. The capacity to maintain the current hydroelectric power is at risk.
Costa Rica (2009)	Three areas that face a high level of water resource vulnerability are 1) the Alajuela province 2) the eastern part of the study area 3) the central zone encompassing the San Jose Metropolitan district. This is due to their high socio-economic vulnerability, which will be exacerbated under conditions of increase temperature and decrease in precipitation.
Cuba (2001)	A reduction in the volume of subsurface waters is predicted and a high risk of salt-water intrusion into the subterranean ground water systems due to sea-level rise
Dominica (2001)	Expected increase in precipitation may expand river volumes and cause surface water contamination due to soil erosion. Water infrastructure may also be vulnerable to damage caused by intense rains. Water consumption may likely increase due to higher temperatures and during periods of low precipitation water resources may be especially vulnerable due to higher usage rates from the agriculture sector. Fresh water resources may be jeopardized due to sea-level rise.
Dominican	Water resources are evaluated as having a "low availability" based on the results of

Republic (2009)	climate models, which predict a reduction by 9% in respect to 1961-1990 levels. If other non-climatic stressors are taken into account such as intensive livestock production or slash and burn agriculture the vulnerability of the water resources may be intensified.
Ecuador (2000)	In most climate scenarios there is a serious to severe shortage in water supplies. Hydro power may be negatively impacted as the Agoyan Project in the Tungurahua province may experience a 23% reduction of inflows during the low water period and the Paute Project in the Azuay province may only be able to meet 45% of its average power capacity.
El Salvador (2000)	Climate models project that by 2085 there may be a reduction in rainfall by as much as 8.9%. Sea-level rise may cause contamination of the ground water supplies. Because of the expected reduction in water resources there will likely be shortages for human and agricultural uses. Also, the reoccurrence of flood events may damage infrastructure and increase sedimentation in rivers.
Grenada (2000)	Enhanced evapotranspiration and reduced surface runoff likely to affect the availability of water supplies. The groundwater resources are likely to be threatened due to the reduction in their recharge. The cisterns located on the Island of Carriacou may be unable to fill due to a reduction in precipitation. Salt intrusion from sea-level rise will reduce the availability of groundwater on the main island of Grenada. Open wells on the Islands of Carriacou and Petite Martinique are located within 100 m of the shoreline and therefore exposed to salt intrusion.
Guatemala (2002)	The MOD-Bal model was used to assess impacts on river flow. In an optimistic scenario there is an increase in flow whereas in a pessimistic scenario there is a reduction by as much as 50% particularly in the highly populated areas of Guatemala, Mazatenango and Quetzaltenango. An increase in temperature and reduction in precipitation will reduce water availability for human consumption and irrigation. The health of the population may be adversely affected from water-borne diseases.
Guyana (2002)	Reduced precipitation yet more intense rainfall may cause water deficits and increase runoff-effecting quality of the rivers. Fluctuations in river levels may cause bank erosion and flooding. Sea-level rise could cause salt-water intrusion into the aquifers impacting the main domestic and industrial water supplies of Guyana. Water demands may likely increase with population growth.
Haiti (2002)	Changes in the river flows and an increase in demand from the growing population will likely cause a deficit in the water supplies. Sea-level rise may cause salinity of freshwater sources.
Honduras (2000)	Changes in the hydrologic cycle are likely to affect domestic water, irrigation and electricity generation.
Jamaica (2000; 2010)	Changes in rainfall are likely to affect water supplies. A raise in sea-level places the groundwater sources and aquifers at risk of salt intrusion. Communities that rely on one water source will be especially vulnerable during extended periods of droughts.
Mexico (2010)	Expected changes in precipitation and temperature are likely to change the water balance. Based on projections of climate, population and economic growth demands on water will create pressure on the country's supplies. Surface water flows are expected to decrease and water supplies are estimated to reach high levels of contamination from high biochemical oxygen demand and chemical oxygen demand.
Nicaragua (2010)	The watersheds of El Tamarindo, Rio Viejo and Guanas are predicted to experience reduced river flows. The pacific coast is most vulnerable to reduced flows, which is exacerbated by deforestation and the high population density. In the central region

	a decrease in water resources will affect agricultural production and hydropower generation. In 2050 there is a noted reduction in the recharge of the aquifers.
Panama (2001)	Sea-level rise threatens the fresh water drinking sources along the coast and the aquifers. Water demand may likely increase for domestic consumption and hydropower generation due to an increase in temperature.
Paraguay (2002)	The average annual precipitation is expected to increase by 18% in 2100 however its variation will cause water stress in some sub-regions. River volumes particularly in the Paraguay and Parana rivers have already showed signs of increase resulting in floods and affecting the quality of the drinking water of the population. Although precipitation may increase, the recharge of the aquifers is not guaranteed.
Peru (2010)	Some studies suggest that by 2050 Peru will have only 60% of the water it has today due to inappropriate uses and the melting of the glaciers. Hydro production may be adversely affected by variability in precipitation and drought conditions. For instance, a growth of 19% in demand for electricity by 2035, combined with the climate change, means that energy production will not be able to meet demands. In the south central region where 2/3 of hydropower production is located, effects of climate change and El Niño will reduce production.
St. Kitts and Nevis (2001)	An increase in precipitation may cause soil erosion and surface runoff coupled with the expected increase in temperatures, evaporation rates may result in an overall reduction in supplies. Sea-level rise will contaminate aquifers by salt water intrusion exacerbating water pressures.
St Lucia (2001)	An increase in sea-level may reduce the quality of drinking water and contaminate irrigation water damaging crops and soils. Intense precipitation events may lead to soil degradation causing siltation of the rivers. Extended periods of drought may also reduce the supply of water available for domestic purposes.
St. Vincent and the Grenadines (2000)	Reduced water supplies will likely have negative implications for hydro power production and agriculture.
Suriname (2006)	The distribution and intensity of precipitation will affect the overall hydrologic cycle. An overall reduction in precipitation will adversely affect energy production, irrigation and potable water supplies. High dependence on waterways for transportation may cause problems for the movement of people and goods around the country.
Trinidad and Tobago (2001)	The Caroni Basin is an important fresh water supply for the Island of Trinidad, which is exposed to sea-level rise. Water supplies across the country are all subjected to reduced precipitation, enhanced evaporation and salt water intrusion.
Uruguay (2004)	Changes in the water supply and the demand are the greatest threat to the water resources. Hydro-electric production will likely be adversely effected by reduction in precipitation, especially in the Central Palma region
Venezuela (2005)	Water supplies are likely to be stressed and higher demands for irrigation will exacerbate the shortages.

Source: Adapted from the National Communication Reports to the UNFCCC for each country.

Table 2 Climate Change Impacts on the Agricultural Sector in the LAC

Country	**Impacts on Agriculture**
Antigua and	High dependence on outside sources for food and changes in global production may

Barbados (2001)	negatively impact the ability to import food. Extreme events may damage local crops. Sea-level rise poses threats to fishery resources
Argentina (2008)	Changes in temperature are likely to have strong impacts on livestock. Although there may be a loss of crops in the northern part of the country, this may be balanced by an increase in production in the south due to more favorable weather conditions allowing for the expansion of the cultivation of fruit and winery crops. In Cuyo future water reductions pose a threat to the fruit and winery production. In Comahue and Patagonia reduction in river flows may have adverse consequences for the irrigation of current crops and the potential to expand the area under production. In the Pampas region, especially dry winters may cause the intensification and spread of fire destroying crops.
Bahamas (2001)	Storm surges and sea-level rise will result in a loss of agricultural land due to salinization. Enhanced CO_2 fertilization may increase crop production but also promote the growth of weeds and invasive species and a reduction in freshwater will ultimately effect ability to grow crops
Barbados (2001)	Production of sugarcane is expected to decrease by 20%-40% resulting in serious social and economic losses. Increasing temperatures will effect vegetable production due to the high soil temperatures, which damage the seedlings. Livestock are also at risk as heat stress may result in a reduction in the production of meat and milk products, disease and death among the animals.
Belize (2002)	Sea-level rise threatens agricultural lands on the coastal plain due to salinization. Intense rainfall may increase soil erosion and availability of topsoil for agriculture. Aquaculture is also threatened by coastal erosion causing turbity in the ponds and a decline in water quality. Storm surges may destroy the ponds and higher sea-level may require aquaculture farmers to relocate. Impacts on coral reefs from bleaching events and storm surges may pose a strong threat to the fisheries industry, which is a significant contributor to the GDP, a large source of employment and nutritional value for the local population. Combined with the projected population growth pressure on food production will be intensified.
Brazil (2010)	Cotton, rice, coffee, sugarcane, beans, sunflower, cassava, corn and soy bean were analyzed and with the exception of sugarcane and cassava there are reductions in the area that could be cultivated for each crop. Livestock may be threatened by heat stress reducing both milk and meat production and effecting reproduction and fertility of the animals. Livestock may also suffer from water shortages as reservoirs dry up. Heat has also caused many chickens to lose body weight and increase mortality.
Bolivia (2009)	In the high plateau region water shortage for livestock and crops is expected, in the Valleys and Chaco regions soil erosion and desertification is projected, and in the Llanos and Amazonia regions a loss of winter crops and livestock due to lack of water, enhanced incidences of pests and disease may be experienced. The shortening of the wet season may reduce crop yields particularly for wheat. An overall reduction in agriculture production in the country will have negative impacts on the income of farmers, but also the quality of the crops will likely be reduced causing a decrease in their economic value.
Chile (2000)	As long as the supply of water is maintained crop production will not be greatly affected however reductions in precipitation in central Chile may reduce yields. Fruit growing may also be positively impacted as the area for production is extended southwards and veins benefit from the attenuation of frost.
Colombia (2010)	The agriculture sector faces high levels of vulnerability from a reduction in precipitation and increase temperatures. 71% of the land used for coffee cultivation is

	threatened, 50% of the pastureland is exposed to a high-very high level of vulnerability. Smallholders are especially at risk with as much as 47% of the peasant economy threatened.
Costa Rica (2009)	The fishing sector may be exposed to rising temperatures causing some commercial species to migrate to other locations. An analysis was carried out on coffee, corn and bean production in the country and determined that an increase in temperature will reduce yields (CEPAL, 2010).
Cuba (2001)	Agro-models were used to assess impacts on crop production showing a reduction in yields for all crops, some such as the potato as high as 40%-45%. Increase in temperature and decrease in precipitation may cause a reduction of 5%-15% of pastureland. Some potato pests such as the "*tizon tardio de la papa*" may decrease in importance but others that are better adapt to the climate changes, such as the "*tizon temperano de papa*" may increase and spread rapidly effecting potato production
Dominica (2001)	Intense precipitation and sea-level rise may cause a loss of topsoil and productive agricultural land. Rising temperatures may cause livestock to lose body weight, reduce fertility and increase incidences of death. A large proportion of the country's economy is derived from agriculture production and it also contributes significantly to the food security of the country, which is likely to be severely impacted.
Dominican Republic (2009)	Based on the WOFOST Model crop yields decrease in all climate scenarios especially in areas that will experience drought and water shortages. Impacts can be differentiated between crops. For instance, crops that are produced under dryland farming such as yuca will be most impacted, whereas rice and sweet potatoes may be better able to withstand the climate changes
Ecuador (2000)	The DSSAT model was used to evaluate the impacts on the potato and tender corn crops in the Guayllabamba river basin and rice, soybean and hard corn in the Guayas river basin. In consideration of future population growth for 2030 there may be pressure on the country's food security as there may be a deficit in 3%-60% of rice production, soybean production may experience a deficit of 3%-5%, potato production may experience a surplus of 120% or a deficit of 34% and hard corn could also experience an increase of 137%-309%.
El Salvador (2000)	Drought conditions may result in a reduction in corn production resulting in economic losses of US$3.1 and US$7.5 million in 2025 and 2100, respectively. Alterations in rainfall may cause fish species to migrate to other areas resulting in potential losses of 16% in the artisanal industry and 23% in the shrimp industry. Reduction in pastures can effect livestock production on the order of 25%-100%.
Grenada (2000)	In order to maintain banana production, irrigation will be necessary increasing stress on water resources. Livestock may suffer from health effects due to heat and drought conditions. The fisheries may be negatively impacted from changes in salinity and impacts on nursery grounds
Guatemala (2002)	The DSSAT model was used to assess impacts on corn, beans and rice production and found that in most cases there is an expected reduction in yields.
Guyana (2002)	Three agricultural areas were studied finding that the region of Leguan is vulnerable to intense rains and flooding causing loss of soil fertility and that in the Mards and Wales regions both may suffer from changes in soil temperature effecting crop production. Sea-level rise poses a risk to agricultural land on the coastal plain. Crops may also be exposed to the spread of pests and disease.

Haiti (2002)	Based on climate projections and the WOFOST agricultural model potatoes, rice and corn show signs of reductions in yields.
Honduras (2000)	Coffee, corn and bean production was analyzed and found that a reduction in precipitation will cause a decline in yields and that the three crops are already close to their temperature thresholds so that increases in temperature will further reduce yields. In fact the agriculture and livestock sector as a whole are at their optimal temperature conditions therefore any increase will adversely affect the industry (CEPAL, 2010).
Jamaica (2000; 2010)	Stronger wind speeds may cause topsoil erosion reducing crop production. Reduced rainfall and drought conditions will further exacerbate crop losses and facilitate the spread of pests and disease. The country's food security is threatened since non-irrigated crops make up the majority of the agriculture production in the country.
Mexico (2010)	Scenarios show that in 2020 moderate reductions in rainfed corn are likely and a loss of 4.2% of land area that will no longer be suitable for its production. Different climate scenarios show that the country may lose from 40% to 85% of its productive land.
Nicaragua (2010)	Based on climate projections and the Ricardian method, corn, bean and coffee production all show signs of reductions resulting in economic losses of 3%, 1%, and 6%of the 2007 GDP in 2100 and the sector as a whole losing 22%. (CEPAL, 2010)
Panama (2001)	The Cocle province is vulnerable to fluctuations in climate, which may reduce rice cultivation and lead to economic losses. However the national rice production may increase by 437 kg/ha in 2010. Corn also shows an increase of 437 kg/ha by 2010 but a reduction of 1670.7 kg/ha and 1045.2 kg/ha by 2050 and 2100 respectively.
Paraguay (2002)	The WOFOST model projects a reduction for soybean by 18,000-50,000 tonne, corn by 16,656-66,624 tonne, sorghum by 4,392-13,908 tonne and cotton 61,360-184,060 tonne per year. The dairy industry may experience a reduction in 15%-20% of milk production due to increase in temperature in addition to impacts on the breeding and health of the livestock. Economic losses in the dairy and meat industry may be on the order of 25% and 12% respectively by 2100.
Peru (2010)	An increase in temperature may enable the expansion of some crops into higher elevation however this may be accompanied by an increase in pests and disease. A reduction in precipitation in the north may alter the growing season of corn and potato, however temperature rises are expected to shorten the growing season for most crops in the country.
St. Kitts and Nevis (2001)	The WOFOST model projects a decrease in sugarcane production and by 2050 rainfed agriculture may not be able to exist without irrigation causing greater pressure on the water supply.
St Lucia (2001)	Coastal agricultural areas may suffer loss of land from salt intrusion. Enhanced storm activity may cause damage to crops, livestock and agricultural infrastructure and drought events may cause stress for livestock and crops resulting in reduced productivity.
St. Vincent and the Grenadines (2000)	Based on the projection of agriculture models, crops yields are expected to decrease. Sea-level rise may cause salt intrusion effecting agricultural land, especially the arrowroot that is an important export crop.
Suriname (2006)	Sea-level rise may cause flooding and salinization of agricultural land along the coast. Changes in the hydrologic cycle (reduced precipitation) will likely have significant losses in crop production especially for rice, bananas, horticulture and livestock.

Trinidad and Tobago (2001)	The Nariva Swamp, an important agriculture area, is exposed to sea-level rise and salt as well as Coconut production along the coast. Sugarcane production is also likely to experience a decrease in production.
Uruguay (2004)	Climate variability will likely increase incidences of pest and disease, cause droughts reducing water availability for irrigation and increase the risk of soil erosion all of which will effect crop. Meat and dairy production will likely decline as animals are exposed to heat and water stress. The quality and quantity of fruit production will likely be exposed to the impacts of salt intrusion and pests.
Venezuela (2005)	Permanent crops are likely to suffer the greatest impacts from a reduction in precipitation and temperature increase. Meat, milk and egg production are all likely to decline due to heat stress among the livestock.

Source: Adapted from the National Communication Reports to the UNFCCC for each country.

Indicators-Based Approach to National Vulnerability Assessments

There is extensive debate in the literature on the merits and shortcomings of using indicators to carry out national vulnerability assessments, to rank countries based on these results and to distribute adaptation funds accordingly (Adger et al. 2004; Klien, 2010; Hinkel, 2011). Below are a few of the key points taken from this discussion:

On Indicators:

- Help to explain complex systems in simple terms
- Results are subjective
- Uses observed data, which increases transparency but overlooks future climate change threats from modeled simulations
- Oversimplifies complex systems but may capture socio-economic conditions, which model simulations may overlook
- Should only be used as an initial assessment to identify areas that require further in-depth analysis
- Are more useful for small scale studies
- No common vulnerability index is likely to be used and agreed upon in the international arena to rank countries level of vulnerability

On National Scale Assessments:

- Difficult to assess vulnerability at the national level due to its geographical distribution and temporal changes
- Limitations in comparing countries due to quality of data and indicators used
- Country’s vulnerability scores change depending on index used
- Results are extremely broad, lack detail and are oversimplified

This study reviewed 35 vulnerability assessments carried out at the globally, regionally (LAC) and internationally in order to identify best practices and limitations to using the indicators-based approach to measure vulnerability. This document presents a summary of the case studies reviewed and some of the key conclusions and recommendations from on the full report.

2. Global Vulnerability Assessments

Several studies and indices have been developed to evaluate and compare vulnerability at the national scale across the globe. Table 3 presents six studies that were reviewed; these studies were selected due to their relevance for evaluating vulnerability to climate change (or natural hazards) and particularly focused on water and agriculture sectors. An assessment of each index/study´s final results is provided in the table.

Table 3 Global Vulnerability Assessments

Index/Study	Type of Assessment	Analysis of Findings
Environmental Vulnerability Index (EVI)[6]	Vulnerability of natural environment to disasters. National level carried out in 235 countries	Does not account for socio-economic conditions. The results are counter-intuitive as many developed countries scored a higher level of vulnerability
Prevalent Vulnerability Index (PVI)[7]	Vulnerability to natural disasters. National scale carried out in Chile, Colombia, Peru, Guatemala, Mexico, Bolivia, Ecuador, Argentina, Costa Rica, Dominican Republic, Trinidad and Tobago, El Salvador, Nicaragua and Jamaica	Limited in usefulness for climate change since few indicators measure natural hazards and climate. Mostly socio-economic conditions are evaluated. Many indicators used in the index are repetitive
Climate Vulnerability Index (CVI)[8]	Evaluates the vulnerability of water resources to future climate change at the community, provincial or national scale. The CVI has been carried out at the national scale for all countries.	Final results at national scale are broad, lack detail and do not indicate where the vulnerable areas are within a country or even between regions (Figure 1). Results are questionable i.e. Honduras

[6] South Pacific Applied Geo Science Commission, 2004 http://www.vulnerabilityindex.net/index.htm

[7] Cardona, O.D., 2007 ; Inter-American Development Bank. http://www.iadb.org/exr/disaster/pvi.cfm?language=EN&parid=4

[8] Sullivan, C.A. and Huntingford, C. 2009. Water resources, climate change and human vulnerability. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009. 3984-3990.

	Future vulnerability is calculated based on projection of indicators under future socio-economic conditions	and the US both scored the same "medium-low" level of vulnerability. Future vulnerability assessment is based on subjective opinion
Global Climate Risk Index 2011 Germanwatch[9]	National scale assessment of the impacts of extreme events based on loss of lives and economic damage	Results show the countries that have been most impacted from extreme events, which are developing nations. The analysis lacks detail and provides limited information on the causes and locations of vulnerability and only accounts for one type of impact from climate change
Ericksen et al.[10]	Vulnerability assessment on the agriculture sector at the national scale for the tropical regions across the globe. Future climate change was based on model simulations and current social and agriculture conditions	Masks variations within countries and even among regions, as the majority of the LAC region tends to show the same level of vulnerability (Figure 2). Study shows that changing the indictor selected modifies where and who is considered to be vulnerable (compare Figure 2 and 3).
Country Notes on Climate Changes Aspects in Agriculture[11]	Vulnerability analysis of the agriculture sector to climate change in 19 LAC countries. Based on current socio-economic conditions	Indicators do not account for different farming types or sizes or crops cultivated factors. Results provide very little indication as to which populations are most vulnerable in the country and where they are located.

Figure 1 presents the results from the CVI and as demonstrated there is very little difference between the countries in the LAC region as almost all of them score a

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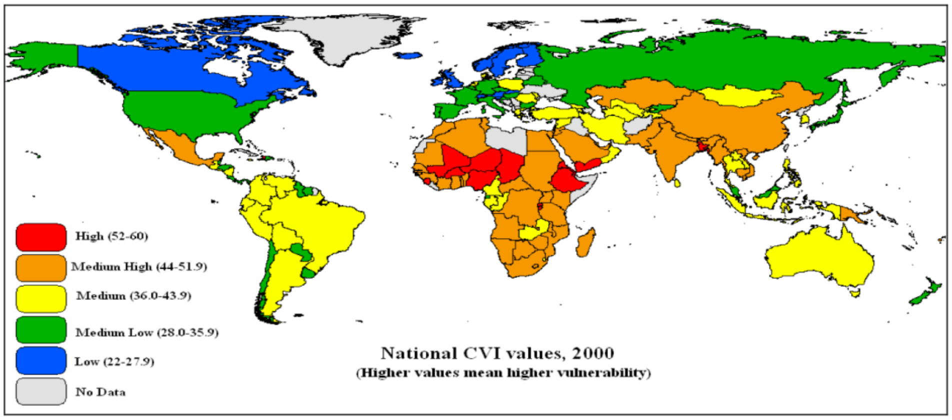
[9] Germanwatch. Harmeling, S. (2011). Who Suffers Most from Extreme Weather Events? Weather-related loss events in 2009 and 1990-2009. Berlin: Germany. http://www.germanwatch.org/klima/cri.htm

[10] Ericksen, P., Thorton P., Cramer L., Jones, P. and Herrero M. (2011). *Mapping Hotspots of Climate Change and Food I security in the Global Tropics.* CCAFS Report no. 5. CGIAR Research Program on Climate Change, Agriculture and Food Security. Copenhagen, Denmark. www.ccafs.cgiar.org.

[11] The World Bank. (2009). *Country Notes on Climate Changes Aspects in Agriculture.* http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/LACEXT/0,,contentMDK:22077094~pagePK:146736~piPK:146830~theSitePK:258554,00.html

"medium" level of vulnerability. Also, some of the results are questionable as countries such as Honduras and Paraguay share the same "medium-low" level vulnerability with the US. Yet comparing this finding with the results from the Climate Risk Index, Honduras is ranked as one of the most vulnerable countries in the world.

Figure 1 Current Level of Vulnerability at the National Scale



Source: Sullivan and Huntingford, 2009.

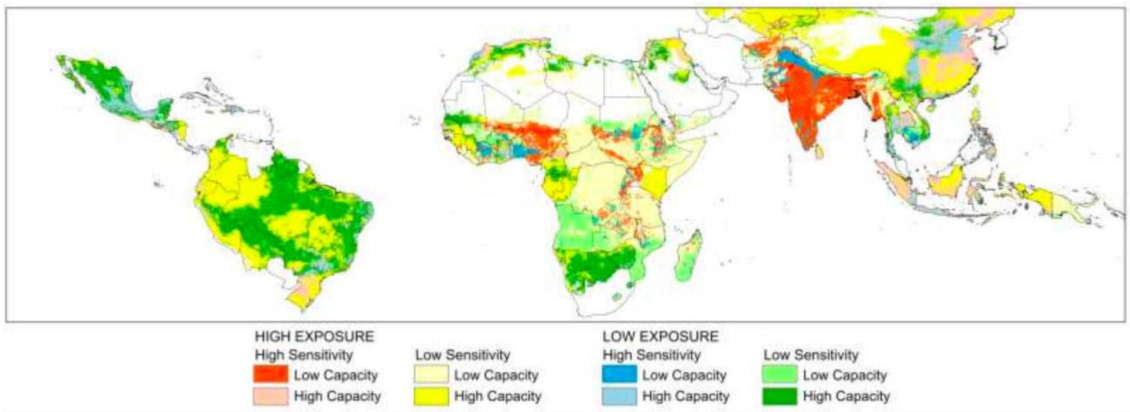
Consequently, the CVI underscores the need to take precaution when using national level studies to determine which countries are most vulnerable since different indicators and data will present divergent results.

Figure 2 and 3 present the results from the Ericksen et al. (2011) study. The evaluation examined current day food insecurity (used as a proxy for adaptive capacity), current agriculture conditions and projected future climate change in the tropical regions in order to assess vulnerability in the agriculture sector at the national scale[12].

Figures 2 and 3 show the spatial distribution of vulnerability at the global scale, however provide no indication of in-country variations or even demonstrate significant differences between the regions.

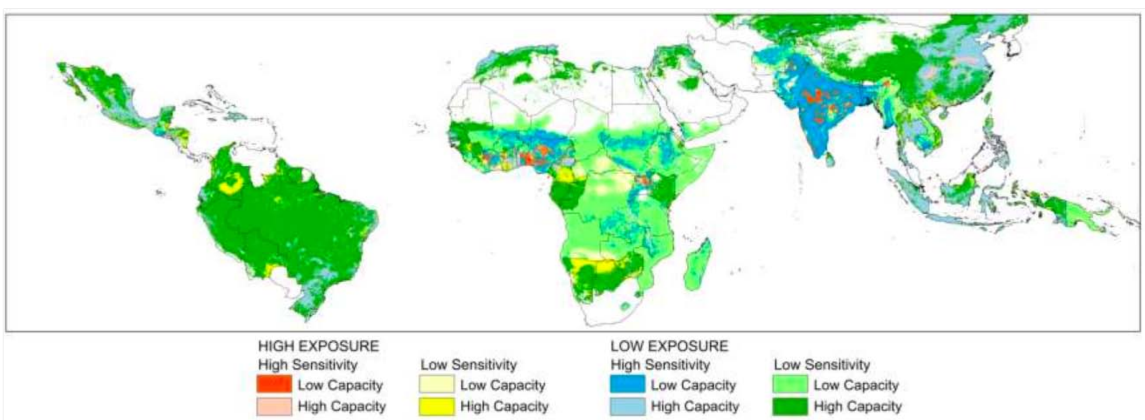
[12] The study only considered agricultural land between the latitudes 35 °S and the 45 °N as such Europe, the US, Argentina, Chile Australia and New Zealand are not included.

Figure 2 Areas where there is Greater than 5% Change n LGP[13]



Source: Adapted from Ericksen et al. 2011.

Figure 3 Maximum Daily Temperature during the Growing Season Flip from <30 deg°C to > 30 deg °C



Source: Adapted from Ericksen et al. 2011.

Comparing the results from Figure 2 and 3 highlights the inherent problems associated with the indicators-based approach since altering the "exposure" indicator modifies the area and amount of people that are considered to be vulnerable. For example, the results using the indicator "*length of growing period changes by more than 5%*" classified 369.1 million people covering a land area of 5,173,000 km^2 under the domain of HHL[14] (Figure 2). Whereas the findings using the indicator "*maximum daily temperature during the growing season changes from*

[13] Length of Growing Period

[14] 8 possible vulnerability domains were used in the study. HHL signifies high exposure, high sensitivity and low capacity and is the highest vulnerability ranking a country may receive. Contrastingly LLH signifies low exposure, low sensitivity and high capacity and is therefore a low ranking vulnerability.

<30 deg C to >30 deg C" classified only 55.8 million people in an area of land covering 888,000 km^2 under the category of HHL (Figure 3), significantly reducing the amount of people and land considered to be highly vulnerable. As such, although the study highlights the areas across the tropics that may be considered "hotspots" the results should only be used as a first level assessment to identity areas that require a more detailed and locally based analysis.

Conclusions from Global Assessments

Several indices and analysis have been developed and carried out at the global scale including: the EVI (SOPAC, 2004), PVI (Cordona, 2007), CVI (Sullivan, 2009), CRI (Germanwatch, 2011), Ericksen et al., 2011 and the World Bank Country Notes (2009). A commonality between these studies is the identification of general indicators that can be easily measured from data that is reported in international databases or at the national level in most countries (i.e. employment in agriculture). The results from these assessments present a very broad analysis of which countries may be most affected by future climate change. Yet, the usefulness of these studies for policy-making and mainstreaming adaptation is questionable as the findings provide very little detail on the causes and distribution of vulnerability within each country. Also, many of the global indices reviewed present results that are either counter-intuitive or conflict with other global evaluations. For instance, the conclusions derived from the EVI show that many European countries experience a higher level of vulnerability than many developing countries in the LAC and African region. Also, depending on the index used some countries score "better" in one assessment than in another. For instance, Honduras scored a medium level of vulnerability on the CVI but on the CRI it is evaluated as one of the most vulnerable countries in the world. These global assessments not only overlook in-country variations but also tend to lump regions into one category of vulnerability as demonstrated Ericksen et al. (2011) and the CVI which both score most of the LAC countries the same. A further limitation highlighted in these studies is that the conclusion on who is vulnerable and who is not is highly dependent on the data and indicators used in the analysis, which have important implications if adaptation resources are distributed based on these evaluations. Ericksen et al. (2011) underscore this point effectively as they show how changing the indicator used in the assessment can significantly modify the number of people and the land area that is considered vulnerable. Consequently, the results from global level assessments appear to be very uncertain and should be taken with caution.

3. Vulnerability Studies from the LAC Region

The review for vulnerability studies carried out in the LAC region in the water and agriculture sector demonstrates that all countries have undertaken at minimum a climate change impact assessment (as presented in their National Communication Report) and a number have conducted vulnerability assessments, which encompass the physical impacts and the adaptive capacity of the location. The studies reviewed in this report were selected due to their methodological approach (indicators-based) and sectoral analysis (water and agriculture) and therefore should not be considered the full range of studies that have been carried out in the region. For instance, the National Institute of Agricultural Technology in Argentina has undertaken significant research on the agriculture sector's vulnerability to climate change however applying future agro-modeling simulations and statistical analysis (Ricardian method) and therefore has not been included in this review. Similarly, the Caribbean Community Climate Change Centre (CCCC) has completed several vulnerability assessments focused on the tourism sector, which is outside the scope of this report. Table 4 presents each LAC study/project reviewed and the analysis of their methodological approach and findings (Table A1 in Appendix A contains more details on the methodological approach and the data sources and gaps). A more detailed description of three case studies is presented and were chosen based on their thoroughness and applicability and adaptability to other countries with in the region.

Table 4 Vulnerability Assessments from the LAC Region

Index/Study	**Type of Assessment**	**Analysis of Findings**
Capacity Building for Stage II Adaptation to Climate Change in Central America, Mexico and Cuba[15]	Each of the 8 countries identified a sector to analyze and the location for the study site. In most cases, water and agriculture were selected and analysis carried out at the watershed or district scale. Indices were constructed to measure current and future vulnerability including the adaptive capacity. Future vulnerability was based on climate change projections and the construction of future socio-economic conditions	A common limitation included lack of data and therefore indicators used to carry out analysis. Future vulnerability assessments are weak and highly uncertain as they are based on subjective socio-economic scenarios. Results often show that areas that have a high level of current vulnerability are the same in the future
The Vulnerability of Water Resources to Climate Change in the North Stann Creek Watershed in Belize[16]	Vulnerability of the water resources in the watershed was determined based on the ratio between water demand and availability evaluated using a vulnerability index and modeling	Study is primarily focused on the physical impacts of climate change on water resources. Findings show that even within the same watershed different types and levels of vulnerability exist

[15] Capacity Building for Stage II Adaptation to Climate Change in Central America, Mexico and Cuba, CATHALAC, 2008.

[16] Belize Enterprise for Sustainable Technology (BEST). (2009). *The Vulnerability of Water Resources to Climate Change in the North Stan Creek Watershed in Belize*. Caribbean Community Climate Change Centre.

	of hydrological resources in the sub-catchment areas. Adaptive capacity was determined from a household survey	
Vulnerability Analysis of Climate Change in the Agricultural, Hydrological and Edaphic Sectors in Chile[17]	A physical, economic and social vulnerability assessment on the agriculture sector covering each region and municipality in the country. Future vulnerability was determined from the combination of current vulnerability and the analysis of future changes in crop yields derived from simulated projections under climate change	Results provide indication of weakness and threats posed to different types of farmers. Future vulnerability assumes an "under business as usual" scenario in which current vulnerability is maintained into the future reducing uncertainties
Colombia Second National Communication Report for the Convention of the UNFCCC[18]	Developed a method at the national scale that could be undertaken for different economic sectors and ecosystems including agriculture and water. Future vulnerability based on projected changes in temperature and precipitation combined with current socio-economic conditions	The final maps show the land areas that are likely to experience the greatest physical impacts from climate change and are most vulnerable due to a low adaptive capacity. Yet the results are limited since it only identifies the surface area of land (ha) that may be exposed to changes in temperature and precipitation
Current Vulnerability to Climate Risks in the Hydrological Resources in the Watersheds of the Rivers Paute, Jubones, Catamayo,	The analysis was carried out on water resources in six watersheds located in different geographical areas. Current vulnerability was evaluated based on present day conditions and historical climate hazards. Future vulnerability was not	The study demonstrates that despite data limitations and without future climate change analysis a thorough investigation may be carried out that identifies the location and causes of vulnerability. The study reduces uncertainties by assuming that current day vulnerability is a

[17] [17]Centro de Agricultura y Medio Ambiente. (2008). *Análisis de Vulnerabilidad del Sector Silvoagropecuario, Recursos Hídricos y Edáficos de Chile frente al Escenarios de Cambio Climático*. Facultad de Ciencias Agronómicas, Universidad de Chile.

[18] Instituto de Hidrología, Meteorología y Estudio Ambientales. (2010). *República De Colombia Segunda Comunicación Nacional Ante La Convención Marco De Las Naciones Unidas Sobre Cambio Climático*. Colombia

Chone, Portoviejo and Babahoyo[19] (Ecuador)	evaluated	good indicator of future conditions, especially if no actions are taken
Climate Change Vulnerability Atlas of Water Resources in Mexico[20]	6 different evaluations on the country's vulnerability to climate change on its water resources: Social Vulnerability, Projected Climate Change in Mexico, Impact of Climate Change during the Rain and Hurricane Season, Vulnerability of the Subsurface Waters, Vulnerability of Irrigated Agriculture and Vulnerability of the Quality of Water	A commonality in each case study is that with the exception of temperature and precipitation data derived from climate models all the evaluations were based on current day quantitative data and in most cases the analysis was carried out at the state and municipal level. Maps created clearly highlight the areas of vulnerability
The Mantaro River Watershed[21] (Peru)	An analysis of the watershed's vulnerability in hydro and agriculture sectors. A socio-economic vulnerability index was developed and statistical analysis was carried out to determine the vulnerability of the agriculture and water sector. Future vulnerability was a qualitative assessment based on population projections and predicted climate change in the watershed	Limitation to statistical analysis is that it only accounted for two variables. Results show that the future vulnerability does not vary significantly from the present day assessment
Santa River Watershed[22] (Peru)	Evaluations were carried out on the biophysical environment, agriculture sector and the socio-economic conditions of the population in the watershed based on current climate variability using information	The results simply highlight the surface areas that are exposed to current and future climate variations.

[19] Ministerio del Ambiente del Ecuador. (2009). *Estudio de Vulnerabilidad Actual a los Riesgos Climáticos en el Sector de los Recursos Hídricos en las Cuencas de los Ríos Paute, Jubones, Catamayo, Chone, Portoviejo y Babahoyo.* Proyecto Adaptación al Cambio Climático

[20] Instituto Mexicano de Tecnología del Agua. (2010). *Atlas de Vulnerabilidad Hidrica en Mexico ante el Cambio Climatico.* Mexico.

[21] Consejo Nacional del Ambiente (CONAM). (2005). *Vulnerabilidad Actual y Futura ante el cambio climático y medidas de adaptación en la Cuenca del Río Mantaro*. Perú. http://cambioclimatico.minam.gob.pe/adaptacion-al-cc/avances-en-el-peru-en-adaptacion/a-nivel-de-cuencas/

[22] MINAM (2009). *Evaluación Local Integrada y Estrategia de Adaptación al Cambio Climático en el Río Santa*. Perú.

	from El Niño (1983 and 1998) and La Niña (1997) and future climate scenarios modeled.	
Adaptation by Agricultural Communities to Climate Change through Participatory and Supply chain Inclusive Management[23]	Community based methodology applied at the farming scale for various systems in the LAC Combines current socio-economic conditions with projected changes in precipitation and temperature and changes in crop suitability	Project highlights that similar agricultural zones and farming systems share similar exposures and sensitivities. Final results provide decision makers with a holistic assessment showing the areas that are most vulnerable and the reason for that the vulnerability
Vulnerability and Adaptation to Climate Variability and Change: The Case of Farmers in Mexico and Argentina[24]	Various farming systems in Mexico and Argentina were analyzed and vulnerability was based on present day socio-economic conditions and impacts from past climatic events in order to postulate how climate change may impact the farming sectors and farmer in each region	The analysis highlights the importance in carrying out more local assessments rather than national level evaluations as each community experienced different types and levels of vulnerability. Also, the farming size and production type was demonstrated to be an important factor in contributing to the overall vulnerability of the farmer

Case Study #1. Vulnerability Analysis of Climate Change in the Agricultural, Hydrological and Edaphic Sectors in Chile

The Faculty at the University of Chile carried out a physical, economic and social vulnerability assessment on the agriculture sector covering each region and municipality in the country.

Methodology

Three indices were constructed to address the vulnerability of the agriculture sector based on the system of production, the social dimension and the economic

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[23] Läderach, P., Eitzinger, A., Bunn, C., Benedikter, A., Quiroga, A., Pantoja, A. and Rizo, L. (2011). *Adaptation by Agricultural Communities to Climate Change through Participatory and Supply chain Inclusive Management.* Methodology. CIAT: Colombia

[24] Gay, C. (2006). *Vulnerability and Adaptation to Climate Variability and Change: The Case of Farmers in Mexico and Argentina*. Project No. LA 29. Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México, México. AIACC Final Reports. The International START Secretariat. http://sedac.ciesin.columbia.edu/cgi-bin/aiacc/webdata_surveys.pl?cgifunction=Search&Code=LA29

conditions. All indices were measured using statistical census and agricultural data and calculated and standardized on a scale of 0-1. Table 5, 6 and 7 present the indices used to evaluate the three components.

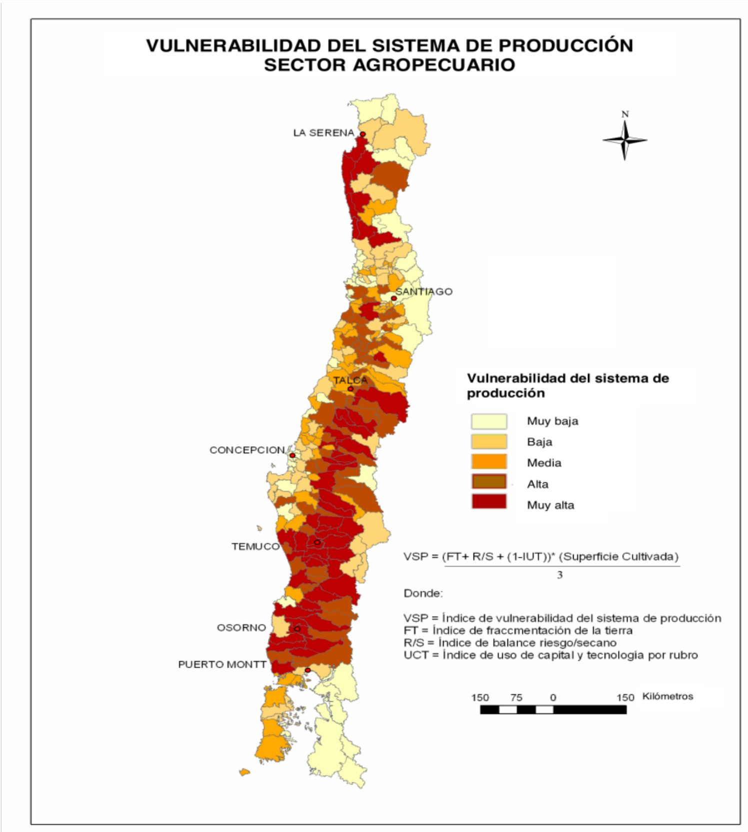
Table 5 Index of Vulnerability of the System of Production (VSP)

Indicator	**Components**	**Explanation**	**Data source**
Index of balance of irrigated /non-irrigated land (IRS)	Surface area non-irrigated/total surface are cultivated	Non-irrigated areas are more exposed to impacts from CC, especially changes in precipitation	National Census on Agriculture and Forestry (2007)
Index of capital use and technology in agriculture (UCT)	UCT total= UCTcrop1* area of crop1*+ UCTcrop2*area of crop2)/total area	Indirect estimate of costs of production and investments and maintenance (including labor, machinery, fertilizers). From a social perspective crops with more technology use and capital are less vulnerable (fruits)	Chile Institution of Statistics (2007)
Index of fragmentation of landholdings (FT)	FT= (k1*ST1+ST2+k3*ST3)/ST Kn= landholding (kn is determined by landholding under 5 hec is small, 10-200 hec medium, over 200 large) STn=community surface area occupied by the stratum of landholding “n” ST= total community surface area (not including protected areas and land not subjected to private ownership)	Communities that have more land under cultivation by smallholders are considered more vulnerable	National Census on Agriculture and Forestry (2007)
Index of vulnerability of the system of production (VSP)	VSP = [FT+IRS+1-UCT]* [cultivate area]/3	Calculated based on the three above indexes To establish an average of the three indexes	

Source: Adapted from the Centre of Agriculture and Environment (CAMA), 2008.

Figure 4 presents the results from the assessment on the system of production mapped for each municipality.

Figure 4 The Vulnerability of the System of Production



Source: Adapted from CAMA, 2008.

Table 6 Index of Vulnerability of the Social System (VSS)

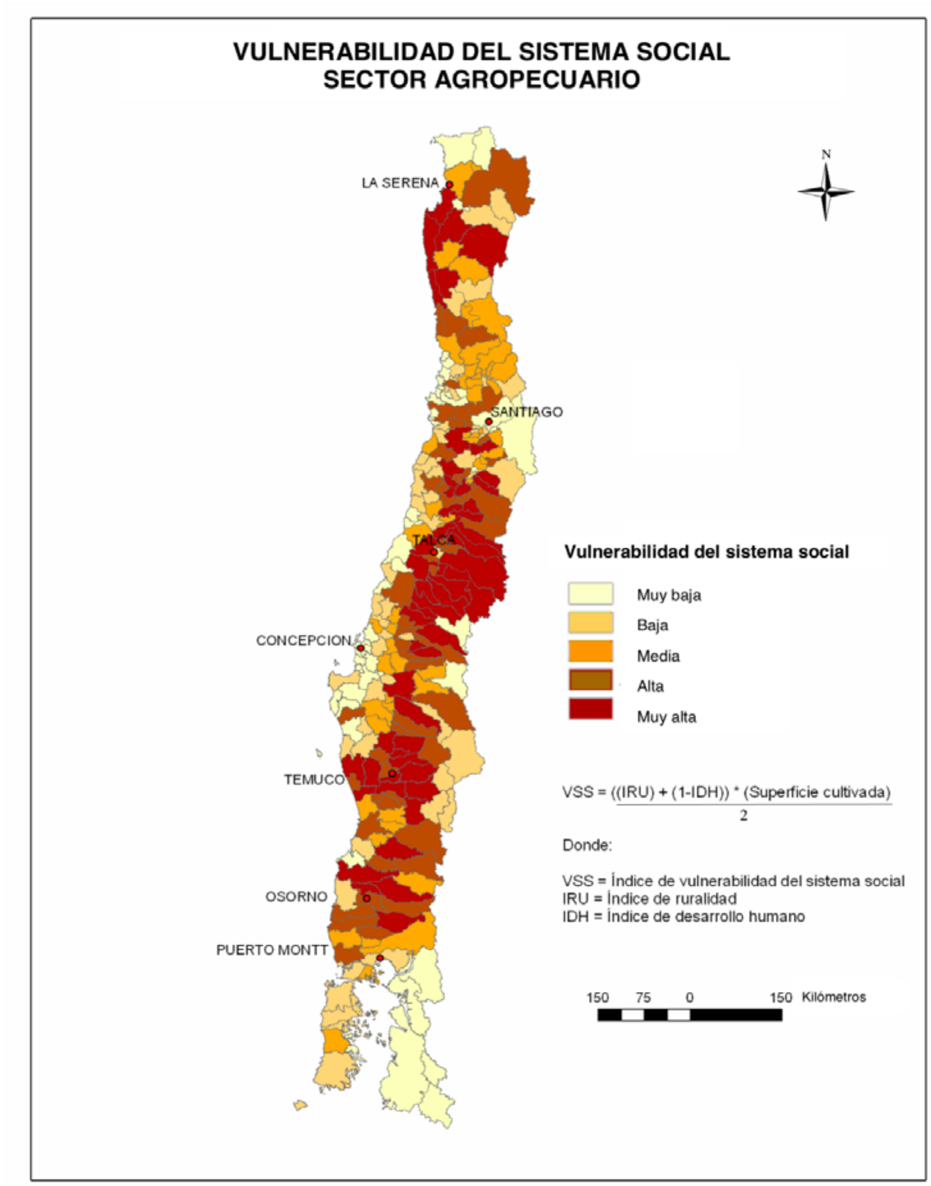
Indicator	Components	Explanation	Data source
Index of Ruralness (IRU)	RU= rural population/ total population in the municipality	Municipalities with a higher level of rural population are more vulnerable (>10,000)	Population Census (2002)
Human Development Index (IDH)	HDI= education + health+ investments Health= Potential years of life lost/hab*1000 Education= adult literacy (<25 years) and average education (<25 years) Investments= education coverage, average investment per capita for housing, average investment per capita in	Represents the level of social development. The IDH is modified slightly from the original UNDP version	Health= Minister of Health 1999-2003 Education= Census of Population 2002 Investments= Survey of the National Socioeconomic

	housing for the poor		Conditions 2003
VSS	VSS = [((IRU)+(1-IDH))]*[area cultivated]/2		

Source: Adapted from CAMA, 2008.

Figure 4 presents the results of the social vulnerability assessment, which was mapped for each municipality.

Figure 4. Index of Vulnerability of the Social System



Source: Adapted from CAMA, 2008.

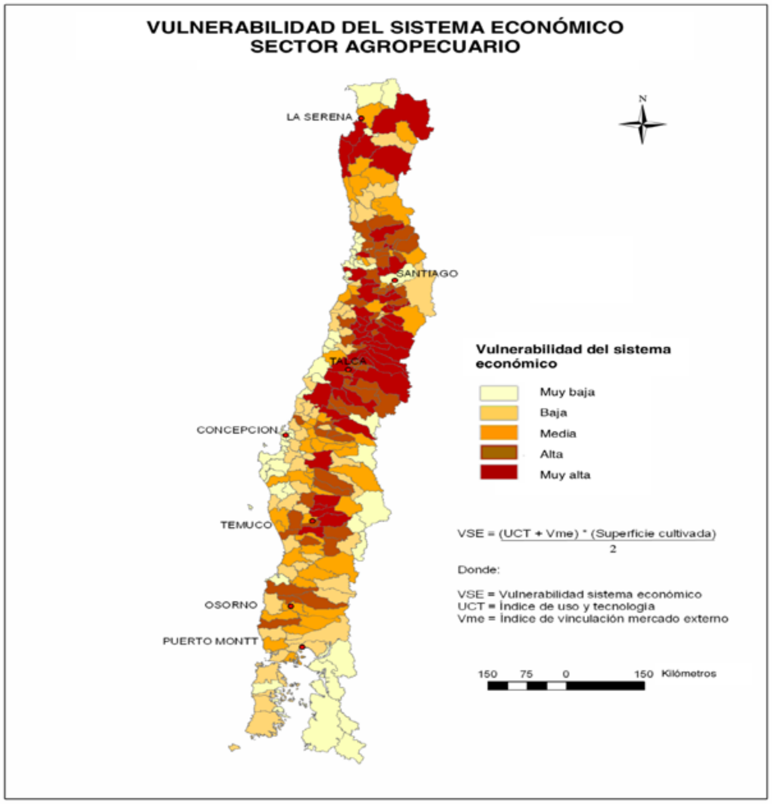
Table 8. Index of Vulnerability of the Economic System (VSE)

Indicator	Components	Explanation	Data source
Index of Capital use and technology (UCT)	See UCT above	Agriculture that is more "industrial" (fruits, grapes) is exposed to greater risks due to larger economic losses	
Connection to external markets (VME)	VME Factors for crops: Seeds:1 Grapes and vineyards: 1 Fruit: 0.94 Industrial crops: 0.69 Vegetables= 0.60 Other annual crops=0.40 Fodder=0.20 Cereals=0.20 Small farm= 0.20	The more dependent on exportation the greater the vulnerability	Estimated based on statistics from Office on Agricultural Studies and Policy 2008
VSE	VSE= [UCT+VME]* {area cultivated]/2		

Source: Adapted from CAMA, 2008.

The results from the economic vulnerability assessment are presented in Figure 5.

Figure 5 Index of Vulnerability of the Economic System



Source: Adapted from CAMA, 2008.

Index of Vulnerability of the Agriculture Sector (VA)

The final VA is evaluated as a function of:

VA= (VSP, VSS, VSE)

Rather than attempting to weight and aggregate the three indices it was decided to maintain them separately as to allow for a clear identification of the precise area of vulnerability that the region or municipality faces, that is, whether it is the system of production, a social aspect or an economic component.

For example VA= 0.5; 0.2;1

Here, this municipality would have a high economic vulnerability but the overall level of vulnerability may be considered moderate since the system of production and social dimensions scored on the lower end of the range.

Impacts of Climate Change on Agriculture

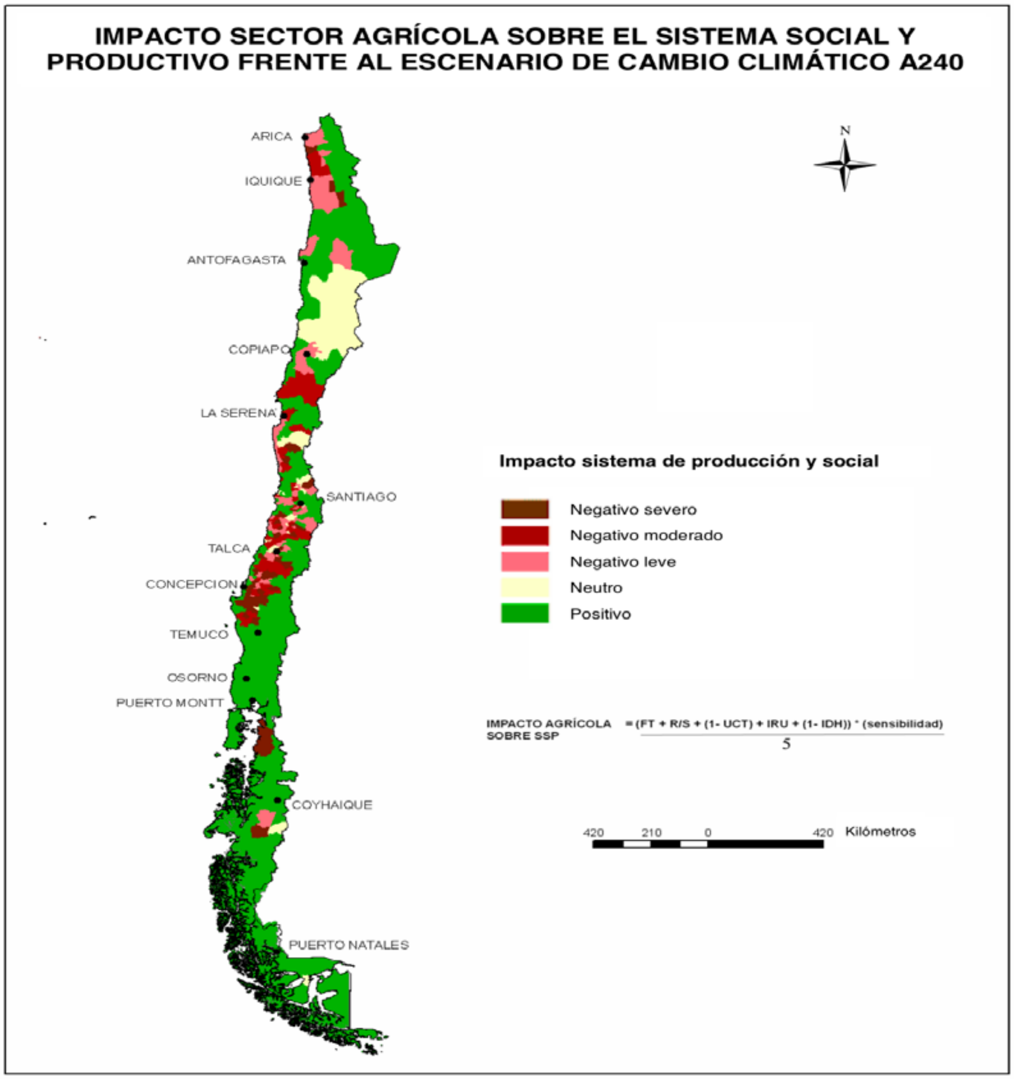
The impacts of climate change on the productivity of crops were evaluated using the SIMPROC (Simulator of the Productivity of Crops), which projected changes in crop yields for various products in every municipality. The sensitivity of the system was calculated as:

Sensitivity= % change in yield* area of crop

The analysis was carried out for 5 irrigated crops including wheat, potatoes, beans, maize and sugar beets. The sum of the variations for each crop was taken and divided by the total surface area under irrigation for each municipality. The analysis was repeated for rainfed crops using cereals as the proxy.

A final index was calculated by combining the evaluations from the current vulnerability of the system production, social or economic conditions with the future sensitivity of the crops. Figure 6 shows an example using the VSP and VSS, which were summed and multiplied by the sensitivity of the crops to derive a result that combines present day social and production vulnerability with future impacts of climate change.

Figure 6 The Impact of Climate Change on the Social and Productive Agricultural Systems



Source: Adapted from CAMA, 2008.

Case Study #2. Climate Change Vulnerability Atlas of Water Resources in Mexico

Vulnerability of Agriculture under Irrigation to Climate Change

An evaluation was carried out on the vulnerability of irrigated agriculture to climate change during the fall-winter season and the spring-summer season at the national scale.

Methodology

A set of physical, social and economic indicators was developed to carry out the assessment. Vulnerability was calculated as a function of:

V= (I-CA) = (E+S-CA)
I= Impacts
CA= Capacity to adapt
E= Exposure
S= Sensitivity

Index of Exposure

The precipitation and temperature data was derived from the General Circulation Model and statistically downscaled for the period of 2071-2098 under the A1 and A2 scenarios. The reference period of 1961-1990 was adopted and calculated based on data from the Climate Research Institute at the University of East Anglia. The Index of Exposure is composed of 5 indicators (Table 9), of which the majority of the data used to measure them was derived from the Mexican Institute of Technology and Water (IMTA) with the exception of hurricane events (Peduzzi, Dao and Herold, 2005) and sea-level rise (CReSIS, University of Kansas).

Table 7 Index of Exposure

Indicator	Measurement
Anomalies in the average daily temperature during the agriculture cycle (vul ↑)	Anomalies projected in °C in the agriculture cycle for the period of 2071-2090 with respect of the baseline
Anomalies in the maximum daily temperature during the agriculture cycle (vul ↑)	Anomalies projected in °C in the agriculture cycle for the period of 2071-2090 with respect of the baseline
Anomalies in the accumulated precipitation during the agriculture cycle (vul ↑)	Projected changes in reduction of accumulated precipitation during the agriculture cycle (%) for the period of 2071-2090 with respect of the baseline
Probability of drought (vul ↑)	Anomalies projected of the Index of Standardized Precipitation for the six months of both seasons for the period of 2071-2090 with respect of the baseline
Frequency of hurricane[25] (vul ↑)	Probability of a hurricane from 1960-2006
Sea level rise[26] (vul ↑)	Area of land inundated with a 5 m rise in

[25] Peduzzi, P.H. Dao and C. Harold. (2005). Mapping Disastrous Natural Hazards Using Global Datasets. *Natural Hazards*. 35 (2). 265-289.
[26] Cresis, 2010. Sea Level Rise Maps. Centre for Remote Sensing of Ice Sheets. University of Kansas, USA.

	sea-level

Source: Adapted from IMTA, 2010.

Index of Sensitivity

Eight indicators were identified to calculate sensitivity (Table 10). The sources of data included the 2007 agriculture census from National Statistic and Geographic Institute (INEGI) and data from the National Commission of Water (CONAGUA), National Council of Population (CONAPO), Information of Agriculture and Fisheries Service (SIAP) and scientific studies.

Table 8 Indicators for Sensitivity

Indicator	Measure	Source
Crop diversity (vul ↓)	The area of crop to the total area of the farm	SIAP
Size of farm (vul ↓)	Area of land under irrigation	INEGI
Rural population (vul ↑)	% of the population under 5000 habitants	CONAPO
Use of fertilizers (vul ↓)	Fertilizer use	INEGI
Precipitation variability (vul ↑)	Standard deviation of precipitation over the base period	Historical data from the Climate Research Unit[27]
Variability in yields (vul ↓)	Maximum yields of corn obtained for the period of 2002-2008 and the municipal level	SIAP
Evapotranspiration (vul ↑)	Annual evapotranspiration	Trabucco and Zomer[28]
Degradation of soils and aquifers (vul ↑)	Soils with infiltration problems and aquifers exposed to salt intrusion or overexploitation	CONAGUA

Source: Adapted from IMTA, 2010.

Index of Adaptive Capacity

Nine indicators (Table 11) were selected to measure adaptive capacity with data derived from the national statistics, SIAP and CONAPO.

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[27] Brohan, P.J.J Kennedy, I Harris, S.F.B. Tett and P.D. Jones. (2006). Uncertainty estimates in regional and global observed temperature changes: a new datasets from 1850. Journal of Geophysical Research, 111.

[28] Trabucco, A and Zomer, R.J. (2009). Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET): Geospatial Database. CGIAR Consortium for Spatial.

Table 9 Indicators for Adaptive Capacity

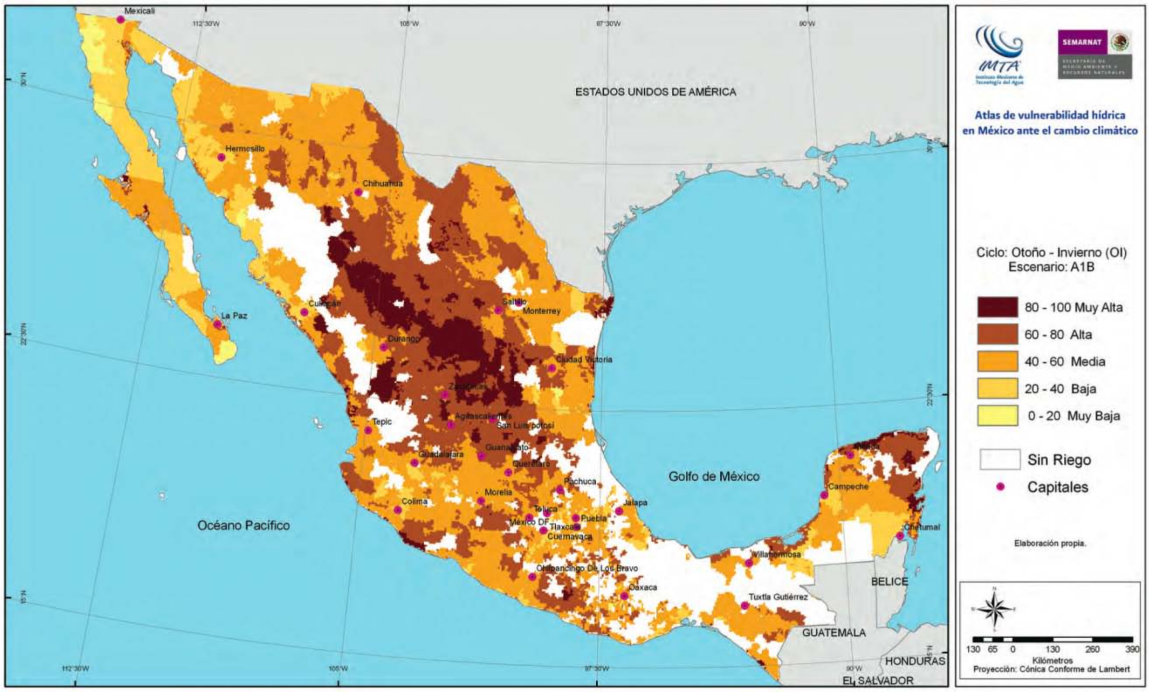
Indicator	Measure	Source
Marginalization (vul ↑)	Level of marginalization	CONAPO
Illiteracy (vul ↑)	% population over 15 that are illiterate	CONAPO
Coverage of services (vul ↓)	% of farmer households with services (potable water, sewage)	INEGI
Dependents (vul ↑)	# of dependents per farmer	INEGI
Access to urban centres[29] (vul ↑)	Time to travel to an urban area	Hodson et al[30]. (2009)
Agriculture income (vul ↑)	% of income of the farmer related to farming activities	INEGI
Intensity of land-use (vul ↓)	% of irrigated crops re-cultivate for the period 2002-2008	SIAP
Mechanization of agriculture (vul ↓)	% of farmers that use machinery	INEGI
Credit/insurance coverage (vul ↓)	% with credit/insurance coverage	INEGI

Source: Adapted from IMTA, 2010.

The data from the three indices of exposure, sensitivity, and adaptive capacity was normalized on an interval of 0-100 and given weights (based on Lyengar and Sudarshan, 1982[31]) in order to derive a global vulnerability score. Maps were created first, for each index and the two growing seasons, and four final maps were created combining the three indices during the winter and summer growing seasons under the A1 and A2 scenarios. Figure 7 shows one of these four final maps.

[29] Hodson, D.P., E. Martinez-Romero, J.W., White, J.D. Corbett, and M. Banziger. (2002). Latin American Maize Research Atlas.
[30] Hodson, D.P., E. Martinez-Romero, J.W., White, J.D. Corbett, and M. Banziger. (2002). Latin American Maize Research Atlas.
[31] Lyengar, N.S. and P. Sudarshan. 1982. A Method of Classifying Regions from Multivariate Data. Economic and Political Weekly. Special Article: 2048-52.

Figure 7 Vulnerability of Irrigated Agriculture to Climate Change (winter A1B)



Source: Adapted from IMTA, 2010.

The maps demonstrate that the areas that are most exposed to climate threats are not always the most vulnerable due to their adaptive capacity.

Case Study #3. Adaptation by Agricultural Communities to Climate Change through Participatory and Supply chain Inclusive Management

Läderach et al. (2011) developed a methodology to assess farmer's vulnerability to climate change at the local scale that could be used in various geographical areas and farming systems.

Methodology

The methodology is based on four stages:

1) Analysis of current and future biophysical suitability of crops
2) Analysis of impacts of changes from stage 1 on the livelihoods of local communities and their adaptive capacity to cope with these impacts
3) Identification of alternative options available to supply chain actors to balance/offset the impacts
4) Development of an adaptation action plan.

In the subsequent sections the general vulnerability methodology is presented followed by some of the initial results from the Nicaraguan case study.

Vulnerability

The study defines vulnerability based on the common IPCC definition, which encompasses exposure, sensitivity and adaptive capacity and a fourth component has been added: “perception of risk” based on the postulation that a household that believes they will be affected by climate change is more likely to implement adaptation measures. To assess vulnerability two methods are applied using a combination of climate and agricultural modeling and socio-economic indicators. *Exposure* and *direct impact sensitivity* are evaluated based on crop prediction models that project the future suitability of key crops under different climatic conditions. *Indirect sensitivity* and *adaptive capacity* are assessed using the Sustainable Rural Livelihoods Framework.   The *perception* of climate change risk is evaluated based on household surveys and interviews.

Climate and Crops

- Current climate data obtained from WorldClim
- Future climate data obtained from global circulation models and simple downscaling applied to the results based on the IPCC emissions scenario SRES-A2 for the periods of 2010-2039 and 2040-2069.
- Crop prediction was based on the calibration of the Ecocrop database from FAO. The model calculates a suitability value for crops based on temperature and rainfall indices
- Land availability was included in the model based on current land uses, protected areas and proximity of road access

Livelihoods and Perception of Risk

To assess the resiliency of livelihoods the available resources in the form of capital stocks are estimated and include:

- Physical capital: road access and dwelling
- Natural capital: water, waste management and land assets
- Human capital: knowledge and food security
- Social capital: organization presence and activities
- Financial capital: credit design and alternative strategies

19 indicators were identified to cover these factors:

- Roads access (quality and distance)
- Transport of products (type and availability)
- Quality of household (material, services)
- Access and availability of water
- Waste management

- Conservation (forest protection on farm, farm management practices)
- Soil conditions and fertility
- Access to formal and informal education
- Level of knowledge of farming systems management
- Household food requirements and food production
- Organizations
- Distribution of work between family members
- Credit access
- Variability of annual production
- Price variability
- Variability in annual revenue
- Income diversification
- Access to market niches
- Access to alternative technology

The perception of risk is evaluated based on whether the household expects an impact from climate change.

Vulnerability Index

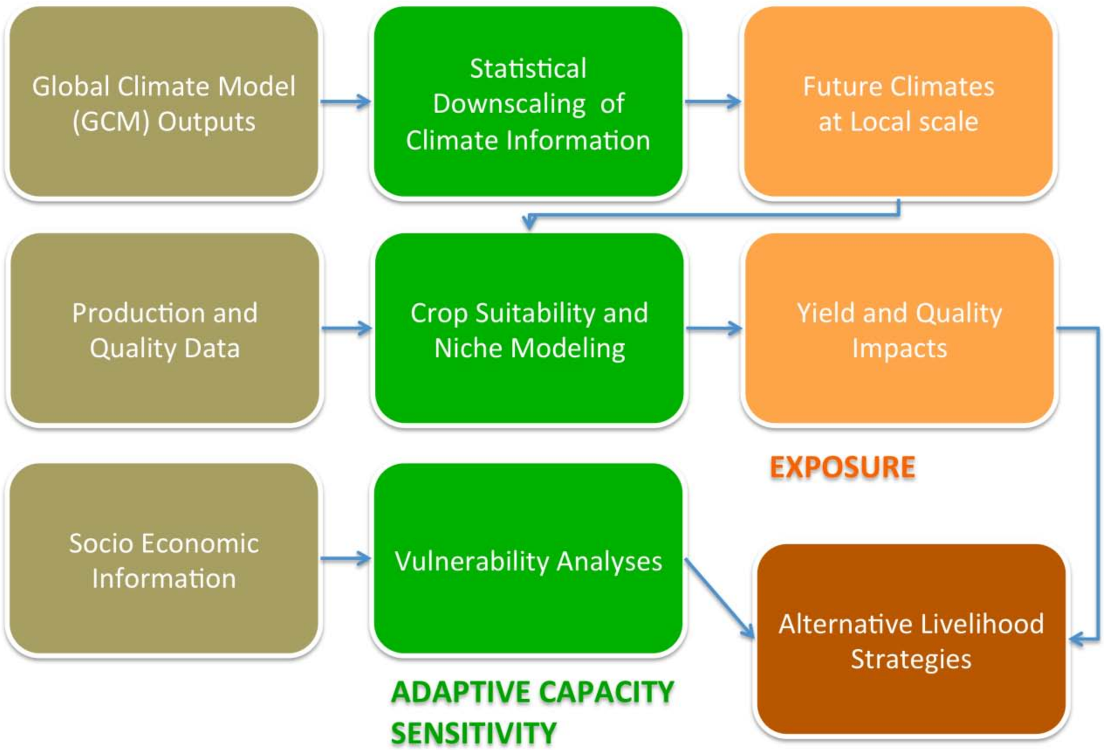
A Vulnerability Index was developed in order to compare the results between different communities. The index includes the biophysical impacts data, the sustainable livelihoods analysis and the socio-cognitive data (from the assessment on perception of risk) to form the following function:

Vulnerability= (Exposure+ Sensitivity)- (Adaptive Capacity + Expected Impact)

All the data is normalized on an ordinal scale of 1 to 3 and the components are given equal weights. The possible results may be from 4-12 with 4 indicating a high level of vulnerability and a 12 demonstrating a high resiliency.

A summary of the methodology is presented in Figure 8.

Figure 8 Methodological Approach

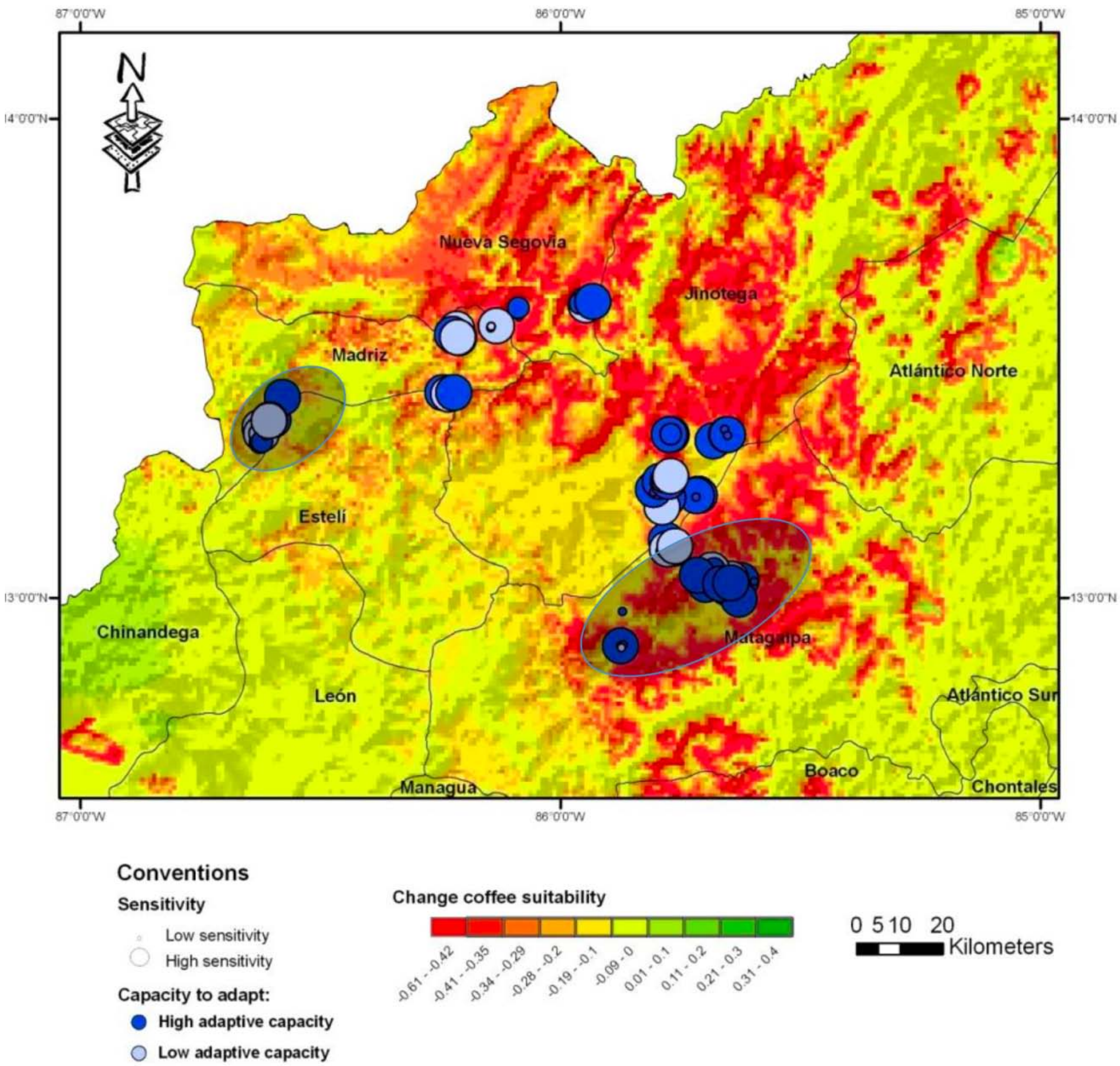


Source: Adapted from Läderach et al. 2011.

Preliminary Results from Nicaragua

The methodology has been applied in several different geographical regions and farming types in Latin America and the Caribbean including the farmers' market value chain in Colombia and Jamaica and the maize-bean system and coffee production in Central America. Some of the preliminary results from the vulnerability analysis in Nicaragua on coffee production are presented in Figure 9.

Figure 9 Vulnerability of Coffee Producers in Nicaragua



Source: Adapted from Laderach et al. 2011.

The map highlights the areas that are most exposed to climate change through the changes in coffee suitability (red zones) overlaid with information on the current sensitivity and adaptive capacity of these zones. Presenting the information in this format clearly identifies the area of weakness in the region (whether it is due to exposure, sensitivity or the adaptive capacity) and therefore helps to direct the types of adaptation measures that should be implemented. For instance, Madriz (located in the northwestern region) is characterized as having a low level of exposure (coffee production will be maintained until 2050), a high level of sensitivity (due to the poor conditions of road and a high variability in yields) and a low adaptive capacity (due to poor organization and a high level of natural resource degradation). As such, the adaptation strategies should focus on conserving natural resources and strengthening institutional capacity. Contrastingly, the Matagalpa province shows a high level of exposure (coffee production is expected to decrease significantly) a high level of sensitivity (due to variability in crop yields) and low adaptive capacity (due to the lack of credit, limited knowledge on pests and crop disease and low levels of crop diversification). As a result, the adaptation strategies should focus on crop diversification, strengthening local capacities and institutional organization.

Conclusions

The vulnerability assessments reviewed in the LAC region and internationally (Appendix 2) vary in terms of the scale of analysis, indicators chosen, the quantity and quality of the data used and the detail and rigorousness of the methodological approach. Regardless of the differences in these studies some common strengths, weaknesses and lessons learned may be identified.

Studies move beyond "impacts": an important strength in many of the assessments reviewed is that most have moved beyond the simple physical "impact" (exposure) analysis and now encompass vulnerability as to include the sensitivity of the system and the adaptive capacity of the population. The inclusion of the adaptive capacity of the population is critical since this is very much tied to the socio-economic conditions of a population, and in most case studies the social vulnerability had a greater influence on the overall level of vulnerability than the climate threats (i.e. CATHALAC, 2008). That is, the segments of the population that presently suffer from poverty and lack social and economic resources are also the ones less prepared to cope with either present day or future climate related disasters. This underscores the urgency to understand, identify and address current social vulnerability in order to reduce the risks from climate change.

Studies highlight that the scale of analysis is critical: the studies clearly highlight that the scale of analysis is critical and that vulnerability is spatially differentiated between countries, regions within the same country (Gbetibouo et al. 2010) populations sharing the same watershed (MINAM, 2009), and importantly even between types of farmers in the same communities (Gay, 2006; CAMA, 2008). Since vulnerability to climate change is context specific, locally based information is required in order to better develop and implement adaptation measures. As such, there is a critical need to scale down the analysis from the global-national level to a more local community-based assessment or ecosystem-based approach, which may require moving beyond traditional political and administrative boundaries.

Studies show that there is no need to separate water and agriculture: studies presented in this review were selected due to their sectoral focus on the water and agriculture sectors. Yet, in most cases studies analyzing the vulnerability of the agriculture also included an analysis on water resources since the sector is so heavily dependent on it. Also, a common characteristic of the "water sector" assessments is that they evaluated based the vulnerability on water resources such as the sources of water (i.e. aquifers and rivers) rather than the analyzing the vulnerability of the end-users (i.e. hydroelectricity).

Data limitations are a clear challenge for many countries: particularly on hydrologic resources, climate, agricultural production and social, cultural and institutional data needed to evaluate adaptive capacity. To overcome this, in the majority of the studies the indicators selected were derived from stakeholder consultations and the type of data available rather than choosing indicators based on recommendations from the vulnerability literature (i.e. Vincent, 2004). Consequently, there is no common "recipe" for each country to follow since the type and quality of data available will differ from country to country.

Building future socio-economic scenarios presents challenges and uncertainties: this has resulted in many studies maintaining a "business as usual" perspective and either 1) evaluating current socio-economic and environmental vulnerability to current climate threats or 2) evaluating current socio-economic and environmental vulnerability combined with future climate change projections. The findings from these types of studies tend to be more accurate and justifiable since they are based on real observable data rather than attempts to project present day conditions into the future. In general, most studies identified that the populations that currently suffer high levels of vulnerability are also the same in the future regardless of the method applied for the future analysis.

Results from indicators-based approach are useful: at small scales the findings indicate the areas and populations that are at a higher risk and the underlying causes for the vulnerability experienced. Since many LAC countries significantly lack data and technical and financial resources to undertake more complex modeling simulations this approach appears justifiable and practical, especially because future modeling simulations often tell the same story as the indicators-based analysis only in different words.

Recommendations

- Global and national level assessments should only serve as a preliminary step in carrying out more detailed analysis at the ecosystem, watershed and/ or farm scale. Vulnerability analysis should move beyond political and administrative boundaries since vulnerability to climate change is more likely to be shared among similar populations in common environments and therefore share adaptation strategies

- Comparing national level vulnerability assessments between countries presents many limitations and should be carried out critically and cautiously as often the indicators and data used vary significantly. Also, most assessments choose one type of climate threat as the focus of analysis, which raises issue of comparing countries that are exposed to droughts and those that are exposed to flood events

- There are no pre-established sets of indicators that can be applied in each country across the region that will provide a clear and detailed analysis and allow for comparisons between countries. For each country to understand their unique vulnerabilities to climate change indicators should be selected based on the data availability in the country

- Regardless of the sector of analysis, vulnerability studies must encompass the exposure, sensitivity and adaptive capacity of the system or population

- The indicators-based approach is recommended over modeling simulations since many countries in the region lack the data requirements and financial and technical resources to carry such assessments that often report similar findings

- The indicators-based approach is useful as a preliminary assessment to identify areas or "hotspots" that may require further detailed analysis and interventions

- Constructing future socio-economic scenarios is fraught with challenges, uncertainties and subjectivity. Evaluating current social vulnerability and maintaining this under future climate change scenarios is appropriate and reduces uncertainties in the assessment

- The importance of the socio-economic conditions cannot be understated and is a key factor in determining a populations overall vulnerability. A recommended approach to evaluating vulnerability at the national scale is to undertake a multi-criteria assessment incorporating social, economic and environmental vulnerability variables and map the results using GIS. Information on future changes in precipitation and agriculture land area may then be overlaid identifying "hotspot" areas, which may then be targeted for more in-depth analysis.

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Glossary

Adaptive capacity: the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences

CNRM-CM3: global circulation model developed by France

CSRIO mk3: global circulation model developed by Australia

DSSAT: an agriculture model that predicts crop growth and yield based on local weather and soil conditions, crop management and genetic information

ECOCROP: an agricultural model based on the FAO database of crop ecological requirements. The model uses temperature and precipitation thresholds to evaluate the suitability of certain crop species to be cultivated in a given area

ECHam5: global circulation model developed by Germany

Exposure: the nature and degree to which a system is exposed to significant climatic variations

HadCM2: global circulation model developed by the Hadley Centre in the UK

IPCC Scenario A2: projects a less dynamic economy, less globalization and high population growth (higher emissions)

IPCC Scenario B2: includes some level of mitigation with more efficient use of energy and clean technology and improved localized solutions (lower emissions)

MIROC 3.7: global circulation model (of medium resolution) developed by Japan

MOD-BAL: water balance model that evaluates the flow of rivers based on precipitation and evapotranspiration data

MODFLOW: a simulation model that assesses the flow of groundwater through aquifers

PRECIS: A regional climate modeling system developed by the Hadley Centre in the UK

Ricardian model: a statistical method used to explain the variation in land value per hectare of cropland over climate zones (Mendelsohn *et al.*, 1994). It has been used to measure the impact of climate change based on the changes in the land value

Resiliency: 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-organisation, and the capacity to adapt to stress and change

Sensitivity: the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)

SIMPROC: projects changes in crop yields under different climate conditions

Vulnerability: the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and 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.

WEAP: a simulation model for water evaluation and planning based on surface and groundwater resources. The model can test various changes in supply and demand over the long term

WOFOST: an agricultural model simulation that analyzes crop growth and production incorporating photosynthesis and respiration and how these processes interact with environmental conditions including weather and soil. The model only considers ecological factors

Appendix A

Table A1 Vulnerability Case Studies from the LAC Region

Country	Scale/Sector Focus	Climate Threat	Current Vulnerability	Future Vulnerability	Data Sources	Data Gaps
CATHALAC (2008) ACCII Studies						
Costa Rica	District (current vulnerability) National scale (future vulnerability) Water Resources	Extreme dry and wet years	15 socio-economic and 7 climatic indicators Weighed and aggregated	12 socio economic indicators projected 2020, climate results from SDSM, qualitative assessment of 6 water/climate and socio-economic factors, final future climate threat matrix created and scored climate and vulnerability arbitrarily	*Current:* Socio-economic data INEC, water balance estimated (World's Water, Reynolds, 1997, MINAE), meteorological data IMN *Future*: Climate change projections from SDSM	Water resource data to determine water balance (present/future), more indicators for water such as per capita consumption, land-use flood and landslide data, more district level information
El Salvador	"Territory" (consists of 100	Extreme events (drought and	69 socio-cultural, economic and	69 socio-cultural, economic and natural	*Current:* qualitative data based on	Need for data at smaller scales i.e deforestation,

	communities, 7 watersheds) divided into 6 geographical zones Human population	precipitation)	natural environment indicators 5 climate indicators (assessed qualitatively based on impacts on agriculture and environmental processes)	environment indicators re-evaluated based on future socio-economic scenarios 5 climate indicators re-calculated based on climate projections	stakeholder consultations, quantitative data based on surveys, meteorological data from one weathering station *Future*: based on qualitative socio-economic scenarios, climate scenarios from SDSM	meteorological data for micro-shed scale
Guatemala	2 watersheds Water and agriculture	Drought and flood events	24 socio-economic indicators, qualitative baseline conditions of water and agriculture sectors presented	Qualitative assessment based on future climate change and pessimistic and optimistic socio-economic scenarios and selected variables and assessed on how they would impact water resources	*Current*: Meteorological data, census data from national statistics, agriculture census data *Future:* SDSM, development of socio-economic scenarios	Data on water resources, climate data, agricultural production, data at the watershed scale for risks to flooding and droughts
Honduras	Watershed Water/ agriculture	Extreme precipitation	16 socio-economic indicators and 2	N/A	*Current*: Meteorological data, primary	Hydrology data to determine water balance

			climatic indicators		data collected (health), agricultural and forestry data	(variations in seasons), climate data that would allow the use of further analysis using different indicators (historical data),
Mexico	Tlaxcala state (community) Agriculture / water	Drought and frost events	Agriculture: Qualitative assessment 7 factors considered Water balance determined	Qualitative assessment based on current vulnerability and future climate risks	*Current:* Qualitative data based on stakeholder consultations, CONAGUA water data *Future:* Climate projections SDSM	More detailed hydrologic data, development of indices to correlate socio-economic vulnerability with the agriculture and water sectors
Nicaragua	Watershed Water/ agriculture	Drought and floods	6 socio-economic indicators, 5 agriculture indicators, 5 water resource indicators	Qualitative assessment based on changes in temperature and precipitation and impacts on water resources	*Current:* Census data, meteorological data, analysis of El Niño and La Niño events, Regional Centre on Disasters in Latin America and the Caribbean, INETER-	Information on agriculture susceptibility to climate and pests etc. Hydrologic data

					MAGFOR *Future:* SDSM	
Cuba	Provincial/ municipal	Drought	23 socio-economic and environmental indicators	Qualitative assessment based on future socio-economic scenarios and climate change projections	N/A	N/A
Panama	Watershed Water	Drought and flood	Qualitative assessment of the socio-economic and environmental conditions	Qualitative assessment based on climate projections	*Current:* Stakeholder consultations *Future:* SDSM	Quantitative data on socio-economic conditions, water resources, agriculture production, meteorological data
National Studies						
Belize	Watershed/ subcatchment areas Water resources	Changes in temperature and precipitation	Current water balance, present adaptive capacity qualitatively evaluated	Climate projections used for estimating evapotranspiration, future demands based on future population and agriculture use, vulnerability index used to calculate level of risk	*Current:* Meteorological data, land-used data, agriculture and population census data, qualitative information on adaptive capacity, population	Ground water data, future land-use scenarios, sea-level rise, socio-economic and institutional quantitative data, future population and agriculture growth

					Future: PRECIS climate modeling,	
Chile	National / municipal Agriculture	Changes in precipitation and temperature (A2)	Quantitative assessment based on Index of Production System, Social Dimensions, Economic Conditions	1) Changes in crop yields for irrigated and rainfed crops per municipality 2) 1+ current vulnerability	*Current*: National statistical population, economic, agriculture, health and education data derived various institutions, investment data from CASEN *Future:* SIMPROC	Water balances
Colombia	National/ regional/ ecosystem Land surface area (including agriculture and water)	Changes in temperature and precipitation	Index of Environmental Sensitivity (5 biophysical factors) Index of Adaptive Capacity (Index Sisben and qualitative assessment of technical capacity)	IES+ precipitation changes, Index of Relative Affectation (potential impacts)	*Current:* IDEAM, IGNAC, stakeholder consultation, DNP, Study on ecosystems *Future*: projected precipitation and temperature PRECIS model, qualitative analysis of potential impacts	Social, cultural and institutional data to access adaptive capacity, quantitative data to evaluate potential impacts
Ecuador	Watershed (6	Flooding,	Climate Threats,	N/A	Meteorological	Limited data on

	geographically dispersed) Water and agriculture	landslides, drought and flashfloods	Index of Exposure to Threat, Index of Socio-economic Vulnerability, Index of Infrastructure Vulnerability, Index of Political Vulnerability		data, maps of morphological characteristics, disaster data (Desinventar), agriculture data, political-administrative units, *Sistema Integrado de Indicadores Sociales del Ecuador*, infrastructure data and management plans	ecosystem and relation to extreme events, precipitation data (quality and number) prevented estimation of frequency of extreme events, agriculture losses at the watershed scale, data at watershed level limited, data on water use and supply
Mexico (IMTA)	State/ municipal Social	N/A	Social Vulnerability based on 15 indicators for education, health, employment, housing and population	N/A	INSP, CONAPO, INEGI	Lack of institutional, social, and cultural data, population's perception of risk
Mexico (IMTA)	State Water/ social	Impacts during rain and hurricane	Index of Danger (precipitation, impact of hurricane)	Precipitation anomalies, changes in atmospheric pressure and wind	*Current*: *Servicio Meteorológico Nacional*, INEGI, CONAPO	Lack of municipal level data, future socio-economic conditions socio-

		season	Index of Vulnerability (population density, GIP, Index of Marginalization) Index of Risk	conditions	*Future*: Japanese climate model	economic data, flood zones and areas susceptible to extreme winds
Mexico (IMTA)	Watershed / river Water	Changes in precipitation	N/A	Changes in precipitation, surface, Index of Precipitation Change, Index of Surface Flow Change, population in municipalities, level of aquifer exploitation, Index of Social Marginalization	*Current:* SEMARNAP, INEGI, CONAGUA (Atlas de Agua en Mexico), CONAPO *Future:* GCM used to calculate changes in precipitation,	Future population changes and water uses, extreme events
Mexico (IMTA)	National Irrigated agriculture	Temperature and precipitation changes, sea-level rise	N/A	Index of Exposure (5 climatic indicators of future changes), Index of Sensitivity (8 agriculture indicators), Index of Adaptive Capacity (9 socio-economic indicators)	*Current:* IMTA, hurricane events (Peduzzi, Dao and Herold, 2005), agriculture data (SIAP, INEGI) CONAGUA, census data (CONAPO) *Future:* GCM	Lack of historical data on variations in water availability for irrigated areas, lack of agriculture data at lower scales, data on farming types and products

					(SDSM), Climate Research Unit, sea-level rise (CReSIS)	
Mexico (IMTA)	3 rivers Water quality	Temperature changes in air and water		Present day pollution levels of BOD, COD and projected under future temperature changes	*Current:* CONAGUA, INEGI *Future:* SDSM under A1B and A2	Lack of water quality data, hydrology and climate information
Peru (Mataro River Watershed)	Watershed/ district scale Agriculture, hydroelectric generation	Frost and drought events, changes in precipitation	Analysis of current climate conditions and variations, Index of Socio-Economic Vulnerability, Agriculture and hydro generation vulnerability (statistical correlation between variable)	Future climate change projections, projection of Socio-Economic Index, qualitative assessment of agriculture and hydro generation based on "current" results and climate and socio-economic projections	*Current:* Meteorological data from SENAMHI, Electrco Peru, Electro Andes and the IGP, national statistics (INEI), agriculture data, energy production data from Mantaro and *Restitución*, from IGP, MINAG and SENAMHI *Future:* GCM projections, qualitative	Limited data available at district level, lack agricultural production data, precipitation and frost events (time and quality), the impacts on the Huaytapallana glacier, water resources (subterranean and water balance), socio-economic information on institutional capacity
Peru (Santa	Watershed/	Temperature	Biophysical	Climate projections	*Current:*	Lack of

River)	district Agriculture, social	and precipitation changes and extreme events (El Niño and La Niña), Social Vulnerability to climate variations	assessment, Ecosystems and anthropogenic activities, agriculture and variations in climate	and agricultural surface area exposed, social vulnerability based on future climate variations and millennium goals	biophysical data (INGMMET), meteorological data from SENAMHI, social data INEI, MINEDU *Future:* Climate scenarios modeled by SENAMHI, millennium goals	meteorological data at the district scale, studies on the local glaciers, socio-economic data

Appendix B

Table B1 International Vulnerability Assessments

Index/Study	Type of Assessment	Analysis of Findings
Gbetibouo, G. A., Ringler, C. and Hassan R. (2010). Vulnerability of the South African farming sector to climate change and variability: An indicator approach.	Vulnerability analysis of the South African agriculture sector at the national and provincial scale. The study incorporates future climate projections with current sensitivity and adaptive capacity conditions	The study assumes that present day social and environmental vulnerability may serve as a proxy for future conditions. The results show that vulnerability to climate change is spatially differentiated across farming regions and within the same country, an important factor to consider for developing appropriate climate change adaptation strategies
Deressa, T., Hassan, R.M. and Ringler, C. (2008). Measuring Ethiopian Farmers' Vulnerability to Climate Change Across Regional States.	Vulnerability analysis of the Ethiopian agriculture sector at the national and provincial scale. The study incorporates future climate projections with current sensitivity and adaptive capacity conditions	The findings highlight the spatial distribution of climate change vulnerability and that the socio-economic conditions of the population play a significant role in the overall vulnerability of the location
Heltberg, R and Bonch-Osmolovkiy, M. (2010). Mapping Vulnerability to Climate Change. The World Bank.	Developed a methodology to carry out a regional scale assessment of the areas that are most vulnerable to climate change and tested it in Tajikistan. The evaluation was undertaken based on current socio-economic vulnerability to climate rather than future scenarios	The study demonstrates that without using any climate change projections or future scenario building vulnerable areas can be identified based on present day conditions. The findings highlight that vulnerability varies across political regions and also agro-ecological zones and that importantly, the socio-economic conditions of the location is an important factor in the overall vulnerability of the population
O'Brien et al. (2004). Mapping vulnerability to multiple stressors: climate change and globalization in India	An assessment of vulnerability of the agricultural sector under two stressors, climate change and globalization. The analysis was carried out at the district level in	Methodology underscores the significance in accounting for the impacts from climate change and non-climatic stressors as it identifies where policy intervention is most critical (areas that are "doubly exposed") and the type of adaptation measures that should be considered

	India	
Vincent, K. (2004). Creating an Index of Social Vulnerability to Climate Change for Africa	This study developed an index to assess social vulnerability to climate change and variations in water resource availability at the national level for African countries. Each country received a final vulnerability score that permits the comparison across countries	The results identify the countries in Africa that experience a high level of social vulnerability yet the assessment of climate change and water resources is very limited as very little climate data and water resource information is incorporated into the SVI. Like other national level assessments the results are very broad
Cutter, D. and Emrich, C. (2009). Oxfam Vulnerability and Climate Change in the US Southeast	The Social Vulnerability Index (SoVI) identifies the population that is most vulnerable to the impacts from natural climatic hazards. The study was carried out in 13 US states including: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Virginia, South Carolina, Tennessee, Texas and Virginia. The assessment is based on current social conditions and exposure to historical extreme events and excepted sea-level rise	The method assumes that present day vulnerability may act as a proxy for future vulnerability to climate change. The strength in the evaluation is that it permits decision makers to identify which counties are most equipped to cope with natural hazards as well as the ability to precisely determine the type of natural hazard that poses the greatest threat to the region or county
International Earth System Sciences Institute. (2006). Vulnerability and adaptation to Climate Variability and Change in Western China.	The AIACC study was undertaken in the Heihe River Basin in northwest China. Two vulnerability assessments were carried out including one on the water resource system in Heihe River Basin under climate variation and a second on	The assessments highlight the importance of carrying out locally based evaluations since even within the same watershed there exists different levels and kinds of vulnerability

	the agricultural sector's vulnerability under climate variation	
Snidvongs, A. (2006). Vulnerability to Climate Change Related to Water Resource Changes and Extreme Hydrological Events in Southeast Asia. AIACC Final Reports	The vulnerability and adaptive capacity of the rain-fed farmer in the Lower Mekong River to climate change was evaluated. The change in rice productivity under different climate scenarios was considered a proxy for stress under future climate change of which the effects on livelihoods was analyzed	Results from the analysis demonstrate the vulnerability of different farmers to climate change based on locally specific data. The study underscores the importance in carrying out local assessments as the results clearly show that vulnerability is "place-based", which depends on the climate impacts and the socio-economic conditions of the region