

Local Vulnerability Indicators and Adaptation to Climate Change

A Survey

Carlos E. Ludena
Sang Won Yoon

Climate Change and
Sustainability Division

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Carlos E. Ludena can be contacted at carlosl@iadb.org or carlosludena@gmail.com

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Abstract

The purpose of this paper is to evaluate interdisciplinary research on vulnerability indexes to climate change. The paper presents a systematized analysis of recent literature on agriculture, coastal areas, water resources, forests and health sectors. The paper examines in particular different aspects of vulnerability indexes to climate change, and emphasizes the importance of deriving vulnerability measures from sector-specific local studies after comparison of various types of sector-specific local institutional arrangement as coping strategies to mitigate climate impacts. The paper also explores possibilities to propose sectoral indices that can be applied systematically at the local level for the practitioners. The survey paper tries to provide pertinent background information regarding the choice of influential variables in the design of field studies and suggests future direction of in-depth empirical research on vulnerability to climate change.

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1. Introduction

In the recent past, vulnerability measures have been used extensively in interdisciplinary research to explain the degree to which a socio-economic and environmental systems suffers from climate change. The popular measure of vulnerability at the earlier stage of theoretical development has been based upon the scientific simulation of economic loss from climate impacts on bio-physical conditions of the environment. Those simulation results depend on the available technology and resources of the communities and organizations affected by an adverse change.

From the socio-economic perspective, however, it is a result of how sensitive a system is to environmental hazards, and how effectively the affected people can act to reduce the detrimental effect of the structural change in climate. The so-called common-pool resources and public goods at multiple scales are required to cope with climate change. Depending on the attributes of the affected communities and sectors and magnitude of climate impact, a diverse set of institutional arrangements at both the local and sector level is expected to emerge. However not all of them are guaranteed to succeed to mitigate the climate impacts.

The potential of a system to adjust to external disturbances and thereby limit risk is usually referred to as adaptive capacity (Smit et al. 1999; Smit and Skinner, 2002; IPCC, 2014 and 2007). Adaptations can be undertaken by individuals, groups or organizations on multiple levels as a response, either in a coordinated manner as a collective action or on an individual basis in an uncoordinated way. The government can either play an active role in the adjustment process or leave the major function of adaptation to private initiatives. The empirical evidence suggests that relative success differs on a case by case basis depending on geographical location, communal attributes, and industrial sectors. Earlier studies on the performance of diverse institutional arrangements in creating and maintaining common-pool resources in coping with external changes in the biophysical environment show that there exists no universally efficient rule of governance that can be applied to vulnerability analysis (Ostrom, 2005, 2009, 2010).

Vulnerability measures thus emphasize the local level case or context. Field research may reveal that neighboring communities respond differentially to climate impact depending on their information and abilities to develop and implement appropriate strategies. For example, farmers who ascertain structural changes in rainfall and soil quality would likely to mitigate external impacts and have to build infrastructure to preserve the biophysical environment as much as possible. They need to collect information on profitability of substitute agricultural products and technology. Due to the lack of access to formal capital markets and technical know-how to build necessary facilities and invest in new crops, farmers may choose to behave in a collective manner and need institutional arrangements to support their actions. It requires a detailed contextual understanding of the relevant systems and how they are impacted by various structural changes.

What makes the measure of vulnerability more difficult is that economic consequences of communal response that we observe through field studies also depend on the socio-economic structural changes such as globalization and financial crisis which take place independently with long-run climate changes. For example, import prices of food and raw materials as well as job market conditions, both at home and abroad certainly affect the opportunity set of local farmers, and influence their response. Most importantly, it requires a careful empirical analysis to separate the contribution of communal or adaptive effort from other conditions that take place in conjunction with these climate impacts. Research in this vein includes double-impact or multiple-impact studies (O'Brien and Leichenko 2000). Most importantly however, a careful design of econometric analysis is required to examine the relationship among the relevant variables.

To investigate causality between climate changes and socio-economic consequence, we need to identify which actors will be impacted, what their roles, positions, information and resources are with respect to adaptation (Smit and Skinner 2002), and to characterize a way to systematize and organize the complex body of data gathered. Any methodology to that end would require understanding

actors' own perceptions of the context of change at the sector-specific local level and how they perceive and rank different risks that results from climate change.

Based upon the assessment of actors' perception and imperfect information on new technology and outside resources, we can evaluate the pattern of ownership in building new infrastructure, the size of business operations, general constraints over time including governance structure such as legal regulations. The complexity of the task may explain why methodologies for vulnerability assessment have been slow to develop (Tol et al. 1998; Fankhauser et al. 1999).

The paper applies such a context-sensitive approach to vulnerability analysis and measurement. It reviews previous research on the performance of particular socio-economic institutional arrangement in an adversely affected biophysical environment and investigates vulnerability assessment at the local-sector level such as agriculture, coastal areas, water, forestry and health. The paper explores a possibility to devise indicators that can aggregate and convey sector-specific information at the local level. Those indicators then become components of the sectoral index that can be applied systematically at the local level

The paper is structured as follows. First, it presents the basic concepts of vulnerability to climate change and the development of vulnerability indexes at a global and national level. Then it presents a review of the efforts to assess local scale vulnerability, including the magnitude of economic loss caused by climate change, and the efforts to develop local vulnerability indicators. The paper then critically reviews the response of local residents for the five selected sectors and examines how the climate impacts and the responses to mitigate impacts can be measured by quantitative or qualitative indicators. The concluding remarks summarize the motivation and content of the paper briefly and suggest further research direction of field studies for vulnerability analysis and measurement.

2. Conceptualization of vulnerability

The definition of vulnerability to climate change is controversial for the same reason why the concept of vulnerability in general is difficult to define. For example,

Watson et al (1996) defines vulnerability to climate change as the extent to which climate change may damage or harm a system, which depends not only on the system's sensitivity but also its ability to adapt to new climatic conditions. Cutter (1996) points out that vulnerability to climate change can be decomposed into three distinct components; risk of exposure to hazards, capability for social response, and attribute of places such as geographical location. He defines vulnerability to climate change as "the likelihood that an individual or group will be exposed to and adversely affected by a hazard."¹

IPCC (2014, 2007) defines vulnerability as a function of exposure, sensitivity, and adaptive capacity. These three components are the key factors in determining a system's vulnerability to climate change and provide useful information for assessing and reducing climatic threats.

Exposure: Climate exposure indicators include temperature rise, heavy rain, drought, and sea level rise. The IPCC predicts that the impact of global warming will continue as the probability of severe heat waves, heavy rain, drought, tropical depression and sea level rise increases over time (Parry et al. 2005).

Sensitivity: The degree of a system's sensitivity to climatic hazards depends not only on geographic conditions but also socio-economic factors such as population and infrastructure. Indicators of sensitivity can encompass geographical conditions, land use, demographic characteristics, and industrial structure such as dependency on agriculture and extent of industrial diversification.

Adaptive capacity: Adaptive capacity describes the ability of a system to cope with climatic extremes. Generally speaking, adaptive capacity to climate change depends on physical resources, access to technology and information, varieties of infrastructure, institutional capability, and the distribution of resources. Indicators for adaptive capacity compose economic capability, physical infrastructure, social capital, institutional capacity, and data availability. Economic capability represents the economic resources available to reduce climate change vulnerability. It includes human resources, technological alternatives and social capital (Yohe and Tol, 2002).

¹ In some literature, vulnerability is interpreted from an outcome perspective and a contextual perspective. See Moss et al 2001; O'Brien et al. 2004; O'Brien et al. 2007; Füssel, 2009.

Physical infrastructure describes the hardware available to enhance adaptive capacity, while indicators of social capital include social network of individual know-how and mutual trust to cope with climate impact. Institutional capability is represented by political leadership and governance structure, disaster prevention systems, and climate change policy. Put more concretely for example, systems of local food supply and distribution, early warning systems, accessibility to relevant information, and availability of crisis management programs and policy are part of adaptive capacity (McCarthy et al. 2001). Some authors explain that adaptive capacity at the local level involves accessibility to political power, specific beliefs and customs (Cutter et al., 2000).

3. Global vulnerability indicators

Füssel (2009b, 2010) examines technical weakness of aggregate indices and point out that the aggregated vulnerability indices cannot adequately consider special circumstances that make certain countries, or groups of countries, particularly vulnerable (or resilient) to climate change. He draws concern that the scientific reviews so far conclude that these generic vulnerability indices are unsuitable for guiding international climate policy due to severe conceptual, methodological, and empirical deficiencies. Despite of growing critics on the methodological issue that arise from aggregation of country-specific characteristics over time, reliability of the data and sensitivity of the choice of proxy variables, there have been various attempts to generate indices of vulnerability to climate change at the aggregate national level.

It has been well known that these aggregate indices typically depend on the ad hoc assumptions on the climate change sensitivity. As a result, a number of studies draw conclusions with remarkably different results and policy implications. (e.g. Moss et al., 2001; Kaly et al., 2004; Brooks et al., 2005; Yohe et al., 2006a, 2006b; Eriksen and Kelly, 2007; Diffenbaugh et al., 2007; Füssel, 2009a, 2009b). For example, using the climate change models, some of these literatures conclude that the poor country is more vulnerable than the rich country (e.g. Mendelsohn, 2001; Tol and Yohe, 2007; Patz et al., 2007). However, there are other literatures, which

draw the opposite conclusion that the rich country is more vulnerable and sensitive to climate variability than the poor country (e.g. Kaly et al., 2004; Yohe et al., 2006a, 2006b; Diffenbaugh et al., 2007). Table 1 summarizes recently developed aggregated indices of outcome vulnerability to climate change.

Table 1. Recently developed indices of countries' generic vulnerability to climate change

Index	Source	Contents	Most vulnerable country identified
Global distribution of vulnerability	Yohe et al. (2006a, 2006b)	Indices of (aggregated outcome) vulnerability to climate change that vary according to different assumptions regarding climate sensitivity, the development of adaptive capacity, and other calibration parameters.	Russia
Climate change Sub index of Environmental Vulnerability Index (EVI-CC)	South Pacific Applied Geoscience Commission (SOPAC)	Considers 50 normalized indicators that represent (i) the risk of hazards occurring, (ii) the inherent resistance to damage and (iii) the acquired vulnerability resulting from past damage. A climate change sub-index (EVI-CC) is defined based on 13 of these 50 indicators: five of them represent the magnitude of recent climate change; four of them represent the exposure and sensitivity of ecosystems; two of them essentially represent land area; and two others essentially represent population density.	European countries (with high population density) , small island states
Indicator of 21st century socio-climatic exposure	Diffenbaugh et al., 2007	Combines data on the severity of regional climate change, economic capacity, and assets at risk. Socioclimatic exposure = climate change index * (population index + wealth index + poverty index).	China and the U.S. East Coast

Source: Füssel (2009b)

Implications for international adaptation funding

If international fund is available to mitigate vulnerability to climate change, the well-designed index of global vulnerability to climate change can provide useful information for two types of decisions regarding allocation of financial resources for international adaptation: classifying countries into discrete vulnerability categories and determining fair allocation of fund for adaptation assistance. Sometimes the ordinal information on the vulnerability of countries and/or of systems and sectors within countries may be helpful to assign countries

to different groups that define their eligibility and conditions for funding (e.g., the fraction of necessary adaptation costs covered from domestic resources). However, to determine “fair” national allocations for adaptation, cardinal quantitative information is needed on the differential vulnerability of countries as well as on their adaptability. (Behrens, 2008; Füssel, 2009b)

Moreover, it should be pointed out that the prioritization of international adaptation assistance involves several normative challenges in addition to assessing countries’ vulnerability to climate change. For example, if the prioritization is based on the aggregate vulnerability index alone, it may implicitly reward countries with poor governance (Füssel, 2009b). Trans-border externalities cause another set of challenges to prioritization. Given the challenges of constructing quantitative aggregated vulnerability indices, sector-specific information on potential climate impacts and adaptive capacity is required for this purpose. Thus, we need more disaggregated vulnerability information that provides information on the specification of conditions for international adaptation funding, to build more appropriate mechanisms.

4. Local vulnerability Indicators

There are two types of approaches to local climate vulnerability assessment. The first type is based on projected impact on a vulnerable region, sector and/or nation. In general, this type of studies utilizes climate change and precipitation scenarios that are based on scientific simulation models. The second type is based on the qualitative analysis of climate change impacts using a matrix of participatory process. The so called ‘bottom-up’ approach has been commonly used for this type of local vulnerability assessment.

4.1. Simulation studies of local scale vulnerability assessment

Simulation studies of local vulnerability often use published data such as sea level rise and precipitation, or follow climate change scenarios. For example, to measure local vulnerability of coastal areas, projected sea level rise has been used as one of factors that affect the vulnerability index from bio-physical domain. In fact, Zeidler (1997) and Yoo et al (2011) conducted an analysis of the pattern of sea level rise over time to measure the impact of climate change from the bio-physical domain in Poland and Korea, respectively. In fact, Yoo et al (2011) conducted both flood and sea level rise simulations and calculated a percentage of flooded area using Geographic Information Systems (GIS) tools.

For the agricultural sector, forecasting models which incorporate a projection of

future climate change are popularly used. For example, Xiong et al (2007) assessed local vulnerability in China by using the concept of thresholds level of temperature and projection of temperature rise over time that can be a threat to crop production. Alcamo et al (2007) used climate and precipitation projection to assess the impact of climate and precipitation during the summer crop growing season in Russia. Conway and Shipper (2011) examined recent climate variability, future climate scenarios and their secondary impacts using information on rainfall (1982-1994), GDP and 18 global climate models to describe future climate in Ethiopia. For South America, there have been several studies that combine socio-economic information with climate models to assess the impact of climate change at the national and local level, using information from household surveys at the municipal level (IDB-ECLAC, 2014a, 2014b; IDB-ECLAC-DNP, 2014; ECLAC, 2014).

Recently, Füssel (2010) points out that there are four climate sensitive sectors where sector or subject specific vulnerability indices are applicable. Table 2 shows how vulnerability indices for these four sectors can be measured.

Table 2. Assessing sector-specific vulnerability: cross-country simulation models

Sectors	Biophysical sensitivity and impacts	Socio-economic exposure	Socio-economic capacity *	Aggregate Social impacts
Water supply	<p>1) Median of the projected change in precipitation;</p> <p>2) Standard deviation of the projected change in precipitation between 1961–1990 and 2040–2069, based on an ensemble of 19 general circulation models (GCMs) that have contributed to the IPCC Fourth Assessment Report (IPCC, 2014, 2007);</p> <p>3) Median of the projected change in runoff simulated by the global hydrological model LPJmL 3.3 for the same period and GCM ensemble (Gerten et al., 2007, 2008).</p>	<p>1) Current population-weighted precipitation, Calculation is based on data from (Balk and Yetman, 2004; Mitchell and Jones, 2005);</p> <p>2) Renewable water resources per person;</p> <p>3) Water use ratio (Mila i Canals et al., 2009).</p> <p>These three indicators measure water availability from renewable sources relative to the inhabited area, the population size, and the current water use, respectively.</p>	<p>1) Percentage of households with improved water supply;</p> <p>2) Percentage of households with improved sanitation (WHO/UNICEF, 2006).</p>	Not available
Food security	<p>1) Simulated change in rainfed yields of 83 cereals according to the G-AEZ model applied to climate projections from three GCMs (Fischer et al., 2002);</p> <p>2) Simulated change in rainfed yields of four staple crops (wheat, rice, coarse grains, and soybeans) according to the DSSAT/IBSNAT crop models applied to climate projections from four GCMs (Parry et al., 2005; Rosenzweig and Iglesias, 2006);</p> <p>3) Agricultural impact of climate change on farm values based on</p>	<p>1) Employment share of agriculture in labor force;</p> <p>2) Share of agriculture in GDP (WRI, 2009).</p>	<p>1) Prevalence of undernourishment based on data from household surveys (FAO, 2008);</p> <p>2) Prevalence of underweight children (de Onis and Blossner, 2003);</p> <p>3) Global Hunger Index, which combines the two previous indices above;</p> <p>4) Child mortality rate (von Grebmer et al., 2008; Wiesmann, 2006).</p>	Not available

	Ricardian analysis (Cline, 2007, based on Mendelsohn et al., 1994; Mendelsohn and Schlesinger, 1999).			
Human health	Current population-weighted temperature, which is a proxy for the health risks from increasing heat waves, calculation being based on data from (Balk and Yetman, 2004; Mitchell and Jones, 2005)	Share of national population in highest risk areas from at least one hazard (Dilley et al., 2005). This indicator comprises weather-related hazards (cyclones, droughts, floods, and landslides) as well as non-weather-related hazards (earthquakes and volcanoes) but more specific data is not easily available	1) Child mortality (UNDP, 2007), which is an indicator of current health status; 2) Predictive indicator of vulnerability (Adger et al., 2004), which was constructed on the basis of 11 socio-economic indicators that correlate strongly with mortality from weather-related disasters at the national level.	Mortality caused by observed climate change, which was estimated for 14 world regions in the WHO Global Burden of Disease assessment (Campbell-Lendrum and Woodruff, 2006; McMichael et al., 2004).
Coastal zones and their populations	1) Percentage of land area below 1 m elevation 2) Percentage of population below 1 m elevation, based on two studies by the World Bank (Buys et al., 2007; Dasgupta et al., 2007 and PLACE-II dataset (SEDAC, 2007). 3) Percentage of land area below 5 m elevation	Fraction of population below 1 m and below 5 m elevation from the PLACE-II dataset (SEDAC, 2007).	GDP per capita (purchasing power parity) (UNDP, 2007). * used as a proxy for coastal protection levels in other global studies of coastal vulnerability to sea-level rise (Delft Hydraulics, 1993; Hinkel, 2008)	Increase in the percentage of population annually flooded according to the global vulnerability assessment (Delft Hydraulics, 1993; Hoozemans et al., 1993)

Source: Füssel (2010)

* **Socio-economic capacity** is additionally measured by several generic factors including: 1) Physical capital stock per capita, Human Development Index (UNDP, 2007), Human assets index (UNCTAD, 2008), Index of human well-being (Prescott-Allen, 2001), Government effectiveness (Kaufmann et al., 2008).

Water supply

Füssel (2010) points out that the biophysical sensitivity and impacts can be measured by the change in regional water supply for a given level of global climate change. He includes median value of the projected precipitation, standard deviation of the projected change in precipitation and median of the projected change in runoff. Socio-economic exposure to climate change impacts on water supply is measured by indicators such as current population weighted precipitation, renewable water resource per capita and water use ratio. He also suggests that the socio-economic capacity can be measured by the proportion of households in the communities or nation that receive improved water supply and sanitation.

Food security

The vulnerability of food security to climate change should focus on local consumers whose food security depends primarily on regionally produced food (Wang, 2010; Füssel, 2010). Given climate change, he suggests that the biophysical sensitivity and impacts can be measured by three indicators that represent the change in farm productivity for a given magnitude of global climate change. His indicators include simulated change in rain-fed yield of 83 cereals calculated from the G-AEZ model applied to climate projections from three Global Climate Models (GCMs) (Fischer et al, 2002), and simulated change in rain-fed yields of four staple crops (wheat, rice, coarse grains, and soybeans) from crop models applied to climate projections from four GCMs (Parry et al., 2005; Rosenzweig and Iglesias, 2006).

According to Füssel (2010), the socio-economic exposure can be represented by the agricultural share of total labor force, and GDP respectively. The socio-economic capacity can be measured by the following three indicators: prevalence of undernourishment based on data from household surveys (FAO, 2008), prevalence of underweight children (de Onis and Blossner, 2003), and Global Hunger Index, which combines the above two indices and the child mortality rate (von Grebmer et al., 2008; Wiesmann, 2006).

Human health

There has been a variety of different approaches that attempt to represent vulnerability of human health to climate impacts. Füssel (2010) aims to include available data relevant for assessing the regional distribution of important climate-sensitive health risks, including those of weather-related disasters. Biophysical sensitivity and impacts are represented by current population-weighted temperature, which is a proxy for the health risks from increasing heat waves (Balk and Yetman, 2004; Mitchell and Jones, 2005). He

also measures socio-economic exposure by the share of national population in highest risk areas from at least one hazard (Dilley et al., 2005). This indicator comprises weather-related hazards (cyclones, droughts, floods, and landslides) as well as non-weather-related hazards (earthquakes and volcanoes).

There are two indicators that Füssel (2010) suggests to measure socio-economic capacity: child mortality (UNDP, 2007) that measures current health status and predictive indicator of vulnerability (Adger et al., 2004) which was constructed on the basis of 11 socio-economic indicators that correlate strongly with mortality from weather-related disasters at the national level. Lastly, impact of climate change on population health is partly measured by mortality. It was estimated for 14 world regions in the WHO Global Burden of Disease assessment (Campbell-Lendrum and Woodruff, 2006; McMichael et al., 2004).

Coastal zones and their populations

The vulnerability of coastal zones and their populations to climate change is described by several indicators. Füssel (2010) introduces sensitivity and exposure indicators that are derived from the two leading researches of global scope which assess the exposure of coastal regions to sea-level rise based on an integration of population and coastal topography datasets. These indicators include percentage of land area and population below 1 m and 5m elevation.

Indicators of biophysical sensitivity consist of the fraction of land area below 1 m and 5 m elevation respectively, and indicators of socio-economic exposure, fraction of population below 1 m and 5 m elevation respectively from the same datasets. Despite the fact that GDP per capita is not specific to coastal protection, he uses GDP per capita to measure socio-economic capacity. He advocates that in the absence of more specific information, per capita income can be used a proxy for coastal protection levels as in other global studies of coastal vulnerability to sea-level rise (Delft Hydraulics, 1993; Hinkel, 2008). Lastly, Füssel (2010) uses indicators such as an increase in the percentage of population annually flooded from the global vulnerability assessment (Delft Hydraulics, 1993; Hoozemans et al., 1993), and an increase in the percentage of population annually flooded (Hinkel, 2008).

4.2. Assessment of vulnerability to climate change at the local level: bottom-up approach

A number of studies on vulnerability to climate change have recognized the necessity of local scale exploration of vulnerability to identify adaptation measures. Measures of global vulnerability to climate change are affected by international agreements

and policies. Although national or international policies may facilitate or restrict adaptation, most adaptive responses will be made at the local level by resource managers, municipal planners, and individuals (Posey, 2009). Furthermore, conclusions regarding vulnerability based on aggregate level assessments may hinder mitigation or adaptation policies. Ignoring the importance of scale dependency of vulnerability can be problematic in terms of understanding and addressing climate change (O'Brien, et al., 2004). So far, however, there has been relatively little attention given to how assessments can be conducted in ways that help build capacity for local communities to understand and find their own solutions to their problems (Fazey et al., 2010; Yoo et al., 2011).

Local vulnerability measure should take into account of the following characteristics to convey information on diverse natural environments and heterogeneous socio-economic structure at multiple scales which lacks in aggregate vulnerability indices.

1) Scale: Many recent vulnerability studies argue that the vulnerability assessment depends critically on the scale of analysis. The vulnerability assessment at the local scale becomes critically important not only because of the bio-physical environmental difference of locations, but also because of the socio-economic contextual differences at the local level. For example, even if we attempt to measure vulnerability to climate hazard (i.e. flood), heterogeneity of locations even within a country or specific region is often responsible for differential response (i.e. coping capability) to that hazard. Furthermore, within a country or region, heterogeneity of socio-economic contexts such as institutions, population, social network and culture, may affect the "local" vulnerability to climate change (Adger, 1999; Carina and Keskitalo, 2008; Engle and Lemos, 2010).

2) Dynamics. Vulnerability assessment requires a dynamic point of view (Liu et al., 2008; Eriksen and Silva, 2009; Frank et al., 2011). However, global scale vulnerability studies that use static proxy variables such as annual GDP may ignore the dynamically changing coping capability at the local scale over a period of time. Individual perception and accumulated knowledge of climate change that evolves over time results from learning through the past experiences of households response to climate change, their attitudes, values, culture and norms. In fact, it has been shown from the number of behavioral studies that individual awareness is one of the critical factors that determine local vulnerability (Vogel et al., 2007). For empirical studies, it is important to characterize individual awareness in a continuously changing environment in an adverse manner.

3) Effective adaptation policy. One of the ultimate goals of assessing local level vulnerability

to climate change is to implement effective adaptation policy and allocate the development assistance effectively. Individual households have been recognized as critical units in designing and implementing effective policy since they play a crucial role bridging between the macro-economic situation and individual welfare (Liu et al., 2008).

4) Diversity. By focusing on micro level unit of analysis such as household or community ecosystem, it becomes feasible to capture the diversity of the natural environment of communities and their socio economic heterogeneity (Adger et al., 2005; Schroter et al., 2005; Flint and Luloff, 2005; Ziervogel et al., 2006; Acosta-Michlik et al., 2008).

In order to create local vulnerability measures that consider above four characteristics, it is necessary to consider measuring the local vulnerability by different sectors. In fact, through various country case studies and projects, we find that sector specific or multiple sector local vulnerability and adaptation measure have been identified at various locations. Practitioners are in great need of the sectoral index that can be applied systematically at the local level. The most commonly examined sectors by local vulnerability assessment studies include agriculture, water, forestry and health.

4.3. Sector specific local vulnerability assessment

Throughout the following sections, we survey case studies of local vulnerability which focus on specific sectors, including agriculture, forests, coastal areas, water resources and health. For each sector, we analyze vulnerability taking into account its three components, namely exposure, sensitivity and adaptive capacity, which are important in determining a system's vulnerability to climate change. Although we find that many indicators which have been identified in local case studies overlap across sectors, some indicators turned out to be sector-specific, distinguishable and exclusive.

4.3.1 Agriculture

Many case studies that adopt bottom-up approach confine their analysis to selected agrarian communities to examine the vulnerability of agriculture to climate change.

Exposure Measure: Object of Vulnerability

The agricultural sector is exposed to climate related hazards from the bio-physical domain (see Kelkar et al., 2008; Ford, 2009; Deressa et al., 2009; Krishnamurthy et al., 2011; Rawlani and Sovacool, 2011). Major hazards include precipitation variability, seasonal temperature change, extreme events such as drought and flood, and sea level rise and intrusion. The exposure measures generally depend on the above mentioned climate driven

hazards and risk.

Sensitivity Measure: Subject of vulnerability

Studies on local agricultural sectors focus on agrarian communities which consist of individual households belonging to different age cohorts at varying locations. Mimura (1999) examined vulnerability of the farmers in low lying coastal areas who are vulnerable to salt water intrusion and destruction of farm land. Hay and Mimura (2006) focused on sensitive mangrove habitats and wet tropic in the small agrarian communities. Some studies emphasize relatively sensitive population (i.e. seniors) in the agrarian communities (Gay et al., 2006; Acosta-Michlik and Espaldon, 2008; Knutsson and Ostwald, 2006; Ben Mohamed, 2011).

Adaptive Capacity Measure

The bottom-up case studies in agrarian communities are usually interested in assessing vulnerability by examining how socio-economic institutions are managed to curb the negative impact of climate change, once bio-physical domain is given. The following aspects of local analysis deserve attention.

Local environmental knowledge for farmers provide observations and interpretations at smaller geographical scales, where systematic meteorological records are often scarce and predictions of climate change and its impacts are most uncertain (Marin, 2010). Community members are likely to prefer and be motivated to carry out particular strategies that align with community values, attitudes and norms. Perceptions can also influence these preferences and motivations which may lead to building community level adaptive capacity.

Household case-study survey results demonstrate that farmer's individual perceptions affect their coping strategies and consequences. In particular, information or knowledge on climate change and its impact to agriculture are found to be one of the significant variables on local vulnerability. A number of studies recognize 'information' variable as an important determinant that formulates adaptive capacity at the local level. For example, semi-structured survey based local vulnerability assessment identified that the awareness and level of knowledge to climate change and its impact on agriculture as one of the key factors (O' Brien et al., 2004; Knutsson and Ostwald, 2006; Hay and Mimura, 2006; Parkins and Mackendrick, 2007; Tschakert, 2007; Deressa et al., 2009; Few and Tran, 2010; Marin, 2010).

In addition, heightened risk perception is linked to community readiness for adaptation. That is, risk perception is connected to adaptive capacity as a trigger for action and mitigation strategies. To extend the concept of risk into vulnerability assessment,

however, risks that stems from environmental hazards are to be compared with physical risks in general (Parkins and Mackendrick, 2007). Carina and Keskitalo (2008) also argue that vulnerability and adaptive capacity are location-specific and many decisions regarding climate-induced risks are made at those levels. Assessments should also include the context of other ongoing changes, such as globalization that will impact communities and exacerbate their vulnerabilities. The results illustrate the need to understand local and regional perceptions of adaptation in formulating appropriate policy measures. They point out that any vulnerability assessment should consider understanding actors' own perceptions of their situation and how they perceive and rank different risks. Climate change may make up only part of the risks that actors need to respond to.

Dependency of income in agriculture is an important aspect of vulnerability and is caused by reliance on a narrow range of limited resources. Such dependency may often lead to social and economic stresses. It can be characterized by the structure and diversity of income, social stability and resilience. In other words, resource dependency and its effects can be captured by reliance on climate dependent resources, variability in such income sources, and migration and other social variables associated with stability and resilience of the community (Adger, 1999).

One of the most common ways to measure local coping strategies to mitigate resource dependency found in local vulnerability case studies are diversification and/or specialization of occupation or crops (Adger, 1999; Bradshaw et al., 2004; Alcamo et al., 2007; Eakin et al., 2007; Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008; Kuruppu, 2009; Liu et al., 2008; Hahn et al., 2009; Deressa et al., 2009; Armah et al., 2010).

Diversification of income sources may be a good strategy to reduce resource dependency and vulnerability of individuals at the household level. However, depending on the circumstances, diversification can also result in increased vulnerability. For example, Liu et al. (2008) suggest that specialization, which is another important adaptation strategy besides diversification is the key to the success of improving the well-being of the farmers. They pointed out that a specialty economy depends on the local leaders and entrepreneurial innovations for promoting their products outside of the village.

Adger (1999) argues that the links between diversification and poverty needs to be carefully examined through for example distinguishing household characteristics of the poor. Information on informal economic activities and their intra-household characteristics are needed as well as demographic factors.

Several case studies argue that informal collective action and the network among

rural farmers are significant variable that affect local vulnerability level (i.e. Adger, 1999; Mimura, 1999; Folke et al., 2002; Knutsson and Ostwald, 2006; Osbahr et al., 2008; Toni and Holanda, 2008; Acosta-Michlik and Espaldon, 2008; Deressa et al., 2009; Few and Tran, 2010; Armah et al., 2010; Ben Mohamed, 2011. For example, Folke et al. (2002) pointed out that by identifying different levels of management (i.e. community-based organizations, boundary and bridging organizations or external policy interventions), it is possible to see how livelihood resilience can be eroded or enhanced. Acosta-Michlik and Espaldon (2008) used farmer's cooperative as a proxy variable for network indicator. Toni and Holanda (2008) argued that farmers using common pastureland have a more diversified system and invest more in a small animal husbandry which are adapted to dry environments.

Few and Tran (2010) investigates how household incomes that are combined with differential entitlements to resources shape patterns of vulnerability to climate extremes. Acosta-Michlik and Espaldon (2008) also include several indicators of economic activities to measure local vulnerability. For example, from socio domain, they included level of household income as well as non-farm source of income. Microeconomic wealth indicators such as household income, expenditures and non-farm income as well as structural variables that affect household income level such as international market price and international trade dependency turn out to be significant variables that affect local vulnerability.

O'Brien et al. (2004) and Eriksen and Silva (2009) have argued that economic variables that are responsible for adding volatility of household income can increase risks in the subsistence-based economies. Examples are the changes associated with economic liberalization, such as commodity price fluctuations and the privatization of former state enterprises (Eakin, 2006; Dicken, 2007; Silva et al., 2008).

Almost all case studies have identified variability of farm and non-farm income as one of the important determinant of local vulnerability. In addition to the monetary measure of farm and off-farm income, Crabbe and Robin (2006) finds that land use characteristics (i.e. crop characteristics) and economic activities (i.e. income from major crops and its proportion to regional income) are critical factor of local vulnerability.

Credit to borrow money from banks also is also referred in the several case studies as it directly relates to household income and management of potential climate driven risks in agriculture (see for example, Acosta-Michlik and Espaldon, 2008 and Deressa et al., 2009).

Fixed assets of farmers such as physical capital can also be significant economic components that form local vulnerability since the value of the physical capital fluctuates over time. Fixed assets may include soil quality (Kelkar et al., 2008), agricultural machinery, agricultural infrastructure such as roads (see for example, Knutsson and Ostwald, 2006; Eriksen and Silva, 2009). Some studies find that irrigation facility is one of the important farmer's assets that reduce vulnerability (Bradshaw et al., 2004; Liu et al., 2008; Alcamo et al., 2007; Knutsson and Ostwald, 2006; Kelkar et al., 2008; Deressa et al., 2009).

Social identity is also identified as a crucial factor that influences both magnitude of adverse impact from climate change and response capacity (Frank et al., 2011). Information on social identity of decision maker is contained in socio demographic characteristics such as age and social status inherited from their parents. Individuals' perceptions of risk of information and self-efficacy often reflect how they see themselves in terms of group membership (Gecas, 1989; Huddy, 2001; Smith, 2007). The way that farmers acknowledge scientists and their knowledge is likely to affect farmers' use of scientific information in making agribusiness decisions.

Frank et al. (2011) explores the relationship of social identity, perception of the validity of information sources, and adaptive motivation in detail through scenario questions with farmers who participated in in-depth interviews. Their survey data and qualitative interviews were used to construct farmers' identities through diverse and overlapping associations, including geographic proximity (areas similarly affected by climate) and place-based ties, occupation (coffee farmer), access to mass media, and participation in cooperatives.

Experience and identity appear to go hand-in-hand. In fact, a number of case studies have included level of education as a proxy measure of social identity that gauges household's or communities' coping capacity (e.g. O'Brien et al., 2004; Hay and Mimura, 2006; Knutsson and Ostwald, 2006; Parkins and Mackendrick, 2007; Tschakert, 2007; Acosta-Michlik and Espaldon, 2008; Kuruppu, 2009; Deressa et al., 2009; Few and Tran, 2010).

A summary of the literature with respect to each component of vulnerability is presented in Table 3.

Table 3. Local vulnerability measure in the agricultural sector

Exposure	<i>Precipitation variability:</i> Gay et al., 2006; Hay and Mimura, 2006; Knutsson and Ostwald, 2006; Priceputu and Greppin, 2006; Alcamo et al., 2007; Kelkar et al., 2008; Deressa et al., 2009; Marin, 2010; Ben Mohamed, 2011; Bury et al., 2011	
	<i>Temperature variability:</i> Gay et al., 2006; Hay and Mimura, 2006; Knutsson and Ostwald, 2006; Priceputu and Greppin, 2006; Xiong et al., 2007; Kelkar et al., 2008; Byg and Salick, 2009; Bury et al., 2011; Rawlani and Sovacool, 2011; Roudier et al., 2011	
	<i>Extreme events:</i> <i>Drought:</i> Alcamo et al., 2007; Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008; Saldana-Zorrilla, 2008; Toni and Holanda, 2008; Eriksen and Silva, 2009; Marin, 2010 <i>Flood:</i> Hay and Mimura, 2006; Priceputu and Greppin, 2006; Armah et al., 2010; Mustafa, 1998 <i>Cyclone:</i> Alcamo et al., 2007	
Sensitivity	Coastal farm	<i>Salt water intrusion and destruction of farm land:</i> Mimura, 1999
	Small rural agrarian communities	<i>Mangrove habitats/Wet tropic:</i> Hay and Mimura, 2006
	Population	<i>Vulnerable age of population:</i> Gay et al., 2006; Acosta-Michlik and Espaldon, 2008; Knutsson, and Ostwald, 2006; Ben Mohamed, 2011; Wang, 2010
Adaptive capacity	Economic	<i>Dependency on rain-fed agriculture or resources:</i> Adger, 1999; Acosta-Michlik and Espaldon, 2008; Armah et al., 2010; Marin, 2010; Ben Mohamed, 2011 <i>Income, non-Ag income:</i> Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008; Toni and Holanda, 2008; Armah et al., 2010 <i>Nominal income, wage, expenditure, disposable income:</i> Gay et al., 2006; Knutsson, and Ostwald, 2006; Toni and Holanda, 2008; Ford, 2009 <i>Domestic price and world price (or openness):</i> Gay et al., 2006; Saldana-Zorrilla, 2008; Eriksen and Silva, 2009 <i>Physical assets (i.e. Animals, vehicles , machines, house and land):</i> Adger, 1999; Knutsson and Ostwald, 2006; Acosta-Michlik and Espaldon, 2008; Toni and Holanda, 2008 <i>Diversification of occupation, crops:</i> Kelkar et al., 2008; Armah et al., 2010 <i>Immigration option:</i> Hay and Mimura, 2006; Saldana-Zorrilla, 2008
	Social	<i>Community Network:</i> Knutsson and Ostwald, 2006; Deressa et al., 2009; Armah et al., 2010

Adaptive capacity		<i>Collective action:</i> Adger, 1999; Toni and Holanda, 2008; Armah et al., 2010; Schwarz et al., 2011
	Infrastructure	<i>Buildings and roads:</i> Knutsson and Ostwald, 2006; Acosta-Michlik and Espaldon, 2008; Toni and Holanda, 2008; Kelkar et al., 2008; Ford, 2009; Schwarz et al., 2011 <i>Water Access:</i> Knutsson and Ostwald, 2006; Alcamo et al., 2007; Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008 <i>Irrigation system:</i> Bradshaw et al., 2004; Knutsson and Ostwald, 2006; Alcamo et al., 2007; Deressa et al., 2009 <i>Public health:</i> Knutsson and Ostwald, 2006 <i>Transportation:</i> Ford, 2009
	Individual knowledge	<i>Awareness of climate driven risk based on past threats:</i> Adger, 1999; Kelkar et al., 2008; Saldana-Zorrilla, 2008; Kelkar et al., 2008; Deressa et al., 2009; Frank et al., 2011; Schwarz et al., 2011 <i>Level of education /cost of education:</i> Hay and Mimura, 2006; Knutsson and Ostwald, 2006; Acosta-Michlik and Espaldon, 2008; Deressa et al., 2009
	Governance	<i>Government social interventions (education policy, farm credit, immigration policy):</i> Marin, 2010; Acosta-Michlik and Espaldon, 2008; Saldana-Zorrilla, 2008; Schwarz et al., 2011

4.3.2 Coastal areas

Exposure Measure: Object of Vulnerability

Coastal zones are also influenced by a geodynamical structure and are highly exposed to threats from adverse climate impacts and socioeconomic activities (Klein and Nicholls 1999; Furlan et al., 2011). Continual flooding, coastal erosion, and loss of livelihood of coastal communities testify to the pressure and vulnerability faced by this unstable environment (McFadden and Green, 2007). Coastal sectors in many different regions are not only one of the most valuable natural assets of the region, but also the most vulnerable front.

Mimura (1999) points out that the primary impacts of sea level rise take the form of increased risk of inundation and coastal flooding, exacerbation of erosion, saltwater intrusion into rivers and underground aquifers and changes in sediments deposition patterns. Many case studies describe how the projected sea-level rise and climate change due to human emissions of greenhouse gas would affect a particular area in the study region (e.g. Chemane et al., 1997; Zeidler, 1997; Dolan and Walker, 2006; Hay and Mimura, 2006;

Harvey and Woodroffe, 2008; Hwang et al., 2009; Yoo et al., 2011).

Some case studies focus on specific climate driven extreme events such as, hurricane, typhoon, cyclones and Tsunami and their impact such as coastal flood on eco system, urban or rural dwellings. For example, Lebel et al. (2011) points out that coastal floods and Tsunami is one of six main flood regimes that are affected by climate change. They identify that coastal farming and fisher communities, tourism dependent communities and small fisher coastal communities and urban dwellings in low-lying areas are vulnerable to the coastal flood and tsunami.

Sensitivity Measure: Subject of vulnerability

The local coastal communities and vulnerable population are commonly referred sensitive units of analysis. However, coastal forest (i.e. Hughes, 2011; Hay and Mimura, 2006), Coastal urban cities (i.e. Zeidler, 1997; Yoo et al., 2011) and Coastal tourism (i.e. Nicholls and Klein 2005; Manuel-Navarrete et al., 2011) are also regarded as sensitive units.

A common theme that emerges out of a number of case studies that focus on coastal area is how to assess climate impact and vulnerability which helps coastal management (Nichollos and Klein, 2005). Given the IPCC (2014) report that the average sea level is projected to rise by 0.18 m to 0.59 m by the end of the 21st century, urban areas near coast is also vulnerable to sea level rise. Vulnerability of coastal cities has been the subject of recent local vulnerability studies. For example, Hwang et al. (2009) reports economic damage from sea level rise in Busan.

For coastal areas, what matters is not the global-mean sea level but the relative sea level of the local area with features of regional sea-level variations and vertical movements of land (Nichollos and Klein, 2005). Several studies argue the importance of relative location in coastal areas in assessing coastal sector vulnerability. For example, Zeidler (1997) examined 4 geologically different “impact regions” in Poland, based on sea level rise scenarios and identified most vulnerable region. Adger (1999) examined social vulnerability through resource dependency and poverty. He considered proximity to the coast as one of indices of vulnerability. Mimura (1999) examined location of population in the low lying areas that decides how many people will be at risk due to sea level rise.

Yoo et al (2011) measures sensitivity to sea level rise in 16 counties in Busan, Korea based on the percentage of flooded area calculated using flood simulation with a GIS tool. The population density and the population at age 65 years and over are also included in the calculation of sensitivity index. Sensitivities to heat waves and heavy rainstorm are quantified using the expert opinions from a survey and information on land use classification.

Adaptive capacity is assessed in three sections: economic capability, infrastructure, and institutional capability. Adaptive capacity is then combined with three different sensitivities, vulnerability to sea level rise, vulnerability to heavy rainstorm, and vulnerability to heat waves.

Dolan and Walker (2006) introduce a case study of assessment of climate change vulnerabilities in the Canada's most sensitive coast, Graham Island. Although they point out the importance of incorporating socioeconomic capacity to cope with climate change with biophysical impacts, their assessment is not based on quantitative results, but based on a qualitative statement emphasizing sensitive landscape, extreme climate variability, and the economic dependence on variables and restricted natural resources. Harvey and Woodroffe (2008) also summarize several efforts to evaluate coastal vulnerabilities in Australia and criticized that there has been little consistency or uniformity in the way in which Australian coast to the impacts of climate change.

Coastal tourism has also been noted as one of the main topic from many local vulnerability studies in developed countries (e.g. Nicholls and Klein, 2005; Manuel-Navarrete et al., 2011). Manuel-Navarrete et al. (2011) examine vulnerability of tourism sector in Mexico, Cancun to increasing frequency of hurricanes. It is reported that despite robust infrastructure and the inflow of foreign capital which has increased coping capacity of Mexican Caribbean, degraded eco-system and undemocratic governance in the region raised overall vulnerability.

Adaptive Capacity: Coping ability

Adaptive capacity indicators that have been identified and related to diversity of income sources in coastal sectors share in common with adaptive indicators in the agricultural sectors. For example, income composition of coastal communities that depend on management of coastal resources such as fisheries, agriculture, tourism and forest affects social welfare of inhabitants (Chemane et al., 1997). Adaptive capacity certainly depends on variability in income. Some measures, however, distinguish adaptive capacity of coastal vulnerability from the other sectors. These include infrastructure such as buildings and roads in coastal areas (i.e. Krishnamurthy et al., 2011), drainage system (i.e. Rawlani and Sovacool, 2011) and natural barrier in coastal areas such as mangrove (i.e. Mimura, 1999; Hay and Mimura, 2006; Hughes 2011).

Table 4 presents a summary of the reviewed literature for coastal areas and its view from the three components component of vulnerability.

Table 4. Local vulnerability measures in the coastal areas

Exposure	<i>Coastal morphological processes (erosion, coastal flood, storm, wetland damage):</i> Zeidler, 1997; Adger, 1999; Mimura, 1999; O'Brien et al., 2004; Nicholls and Klein, 2005; Rawlani and Sovacool, 2011	
	<i>Extreme events (e.g. Tsunami , cyclones):</i> Hay and Mimura, 2006; Krishnamurthy et al., 2011	
	<i>Sea level rise:</i> Chemane et al., 1997; Zeidler, 1997; Yoo et al., 2011; Mimura, 1999	
	<i>Heavy rainstorm (daily precipitation greater than 80 mm):</i> Yoo et al., 2011	
	<i>Heat wave:</i> Yoo et al., 2011	
Sensitivity	Costal location	<i>Salt water intrusion, destruction of farm land or destruction of houses near the coast.</i> Adger, 1999; Mimura, 1999; Hughes, 2011; Hay and Mimura, 2006; Rawlani and Sovacool, 2011
	Coastal forest	<i>Mangrove habitats:</i> Hughes, 2011 <i>Wet tropic:</i> Hay and Mimura, 2006
	Coastal ecosystem	<i>Coral reef:</i> Mimura, 1999; Hay and Mimura, 2006; Hughes, 2011
	Small fisher coastal communities	<i>Decreasing productivity due to climate variability and extreme events:</i> Lal et al., 2011; Nicholls and Klein, 2005; Schwarz et al., 2011
	Coastal Urban cities	<i>Business and local economy that are based on coastal region:</i> Zeidler, 1997; Yoo et al., 2011
	Costal Tourism	<i>Hotels and resorts:</i> Nicholls and Klein, 2005; Manuel-Navarrete et al., 2011
	Population	<i>Increasing vulnerable population (e.g. Over 65):</i> Chemane et al., 1997; Zeidler, 1997; Mimura, 1999; Hahn et al., 2009; Rawlani and Sovacool, 2011; Yoo et al., 2011
	Adaptive capacity	Economic
Social		<i>Community Network:</i> Mimura, 1999; Hahn et al., 2009 <i>Collective action:</i> Adger, 1999; Schwarz et al., 2011; Manuel-Navarrete et al., 2011
Infrastructure		<i>Buildings and road in coastal areas:</i> Mimura, 1999; Krishnamurthy et al., 2011; Yoo et al., 2011 <i>Drainage system:</i> Rawlani and Sovacool, 2011 <i>Health status (i.e. Average time to health facility):</i> Hahn et al., 2009; Yoo et al., 2011
Individual knowledge		<i>Awareness based on past threats:</i> Adger, 1999; Yoo et al., 2011; Schwarz et al., 2011
Governance		<i>Government social interventions:</i> Schwarz et al., 2011
Natural Barrier		<i>Coral reefs/ Mangroves and sandy beaches:</i> Chemane et al., 1997; Mimura, 1999; Hay and Mimura, 2006; Hughes, 2011

4.3.3 Water supply

Exposure Measure: Object of Vulnerability

Impacts of climate change on water availability and quality, for example, is likely to threaten the sustainability and increase the risk for social and ecological systems. Climate rise would accelerate the spring snowmelt and result in faster and earlier spring runoff. Mountainous areas with such runoff would be particularly vulnerable to increased flooding. In general, flood frequencies are most likely to increase in the higher latitudes where the GCMs project the largest increases in precipitation, in basins where snowmelt is a primary determinant of runoff, and in coastal areas with higher sea levels and increased storm surges (Frederick and Schwarz, 1999; Crabbe and Robin, 2006; Alcamo et al., 2007; Acosta-Michlik and Espaldon, 2008; Liu et al., 2008; Kelkar et al., 2008).

In addition, water sector is exposed to extreme events such as droughts and floods. According to IPCC (2014) reduced precipitation, evapotranspiration, and more frequent dry spells can bring forth higher frequency and greater intensity of droughts in some areas. Lal et al. (2011) points out that possible limitation on water supply by projected temperature increases in the region becomes more serious if the rain and snowfall in the spring months is reduced substantially. They also pointed out that as regional and seasonal precipitation patterns change and rainfall becomes more concentrated in heavy events, floods are also projected to be more frequent and intense.

Sensitivity Measure: Subject of vulnerability

Water sector has been regarded as an extremely sensitive sector to climate change precipitation variability (Füssel, 2009). As water quality and availability become increasingly stressed with climate change, the ability to absorb these stresses and cope with new realities and potential future surprises becomes critical (Engle and Lemos, 2010). Globally, the potential impact of climate change on water resources has been the subject of analysis for over a decade, and there is evidence that freshwater resources are vulnerable globally (Bates et al., 2008; Farley et al., 2011)

Impacts of climate change on water availability and quality, for example, is likely to threaten the sustainability and increase the risk for social and ecological systems. Adaptive measures to cope with hydrologic fluctuations require the costs of building and managing infrastructure to provide more even and reliable flows. Furthermore, the probability of facing droughts and floods remains non-negligible despite the sizeable investments to control flood waters and increase available supplies. Given the infrastructure of the community, climate change could alter both the frequency and magnitude of large floods. The IPCC (2014)

concludes that a greenhouse warming is likely to increase flood frequencies in many areas, although the magnitude of the increase from any climate scenario remains uncertain and the impacts will vary by region.

Since agricultural products are most susceptible to short-term and prolonged water shortages, rural communities that highly depend on water resource for agriculture are common units of analysis in local vulnerability studies (i.e. Acosta-Michlik and Espaldon, 2008; Liu et al., 2008; Kelkar et al., 2008). Droughts may result in reduced crop production, soil losses from dust storms, or higher water costs.

Environmental resources such as fish and trees may have suffered the most severe impacts of this prolonged drought. Milly et al. (2008) suggest that the eastern part of the country will experience increased runoff, accompanied by declines in the west (e.g. Southwest region of U.S). This means that wet areas are projected to get more wet and dry areas drier, thus increasing the vulnerability of agricultural and forest-dependent communities whose livelihoods (or incomes) in many cases are sensitive to water availability. Urban water users may be subjected to higher water expenses and residential users may also be required to conserve water.

Population growth in these arid and semi-arid regions could also stress water supplies. The impact is likely to become more severe for urban centers than rural counties. Farley et al. (2011) points out that vulnerability to climate change in the water sector may vary by location and the amount of water use. In addition they point out that the demographic growth exacerbates the impact of climate change in water supply sectors. In fact, it has been pointed out by many studies that the joint effect of climate change and population growth will profoundly affect the availability and quality of water resources (Conway and Hulme, 1996; Sánchez et al., 2004; Milly et al., 2005; Evans, 2008).

Adaptive capacity: Coping ability

Governance or management policies of water resource and water resource stock have been identified as important determinants of local adaptive capacity. For example, several studies examine the role of governance and political drivers in the water sector vulnerability in various locations (i.e. Engle and Lemos, 2010 for Brazil; Sowers et al., 2009 for North Africa). These reforms have ranged from the full-fledged privatization of water systems to different degrees of decentralization and societal participation of water governance in the implementation of adaptive management approaches. In Brazil, the government has implemented a new decentralized water management system which adopts the river basin as the management unit, creates stakeholder-driven river basin councils and

consortia, redefines water as a public good with economic value, and seeks to integrate social and ecological systems into water management (Engle and Lemos, 2010). Their findings indicate that these governance mechanisms might lead to greater adaptive capacity, and that tradeoffs may exist between some of the variables (e.g., equality of decision making and knowledge availability).

Knowledge of water resource stock and local cultural value of the water resource have been identified as important components of adaptive capacity in water related sectors. For example, Kelkar et al (2008) finds that community perception of climate driven water stress plays a key role in local vulnerability in India. By using a projection of water availability, they identified four distinct impacts from decreasing water supply in the region such as reduced availability of ground water availability as well as surface water, reduced water quality and declining crop. In the studied region, they find that community coping strategy of the water shortage consists of improving access to available water, reduction in demand for water and increasing risk management skills by diversifying crops, occupation and asset portfolio.

Kuruppu (2009) argues that what is most fundamental to water management and adaptation planning is the integration of people's cultural values attached to the assets/resources they control and utilize their efforts to adapt to various stresses on water resources in Kiribati. She finds that diversification of water resources and a coping strategy adopted by the Kiribati during droughts have the potential to enhance adaptive capacity to the combined impacts of climatic and non-climatic stresses. On the outer islands households diversify water resources by accessing standby wells which are located away from the coast in bushland areas. They also borrow rainwater from churches or neighbors with tin roofs. Furthermore, she argues that adaptation initiatives include possession of their own rainwater tanks, cement lining of open wells and installment of locally designed hand pumps.

Table 5. Local vulnerability measures in the water supply sectors

Exposure	<i>Droughts -damages are likely to rise as water resources become increasingly scarce and some water supply systems have less capacity to compensate for shortfalls:</i> Frederick and Schwarz, 1999; Alcamo et al., 2007; Acosta-Michlik and Espaldon, 2008; Liu et al., 2008; Engle and Lemos, 2010	
	<i>Flood- damages have been rising over time and are likely to continue rising as floodplain development places more people and property at risk:</i> Frederick and Schwarz, 1999; Engle and Lemos, 2010; Farley et al., 2011	
	<i>Daily precipitation, temperature (Mean, Min , Max) , climate model:</i> Frederick and Schwarz, 1999; Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008	
	<i>Mean annual precipitation, Mean annual potential evaporation:</i> Kelkar et al., 2008	
Sensitivity	Water dependent sector	<i>Rural community depends on agriculture:</i> Acosta-Michlik and Espaldon, 2008; Liu et al., 2008; Kelkar et al., 2008
	Population	<i>Drinking water increase due to population growth:</i> Frederick and Schwarz, 1999
Adaptive capacity	Economic	<i>Land use:</i> Alcamo et al., 2007; Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008 <i>Income:</i> Frederick and Schwarz, 1999; Acosta-Michlik and Espaldon, 2008 <i>Housing location (e.g. landslide prone areas):</i> Acosta-Michlik and Espaldon, 2008 <i>Flexibility of occupation, migration:</i> Kelkar et al., 2008; Lal et al., 2011 <i>Diversification of water resource:</i> Alcamo et al., 2007; Kuruppu, 2009 <i>Physical assets (Ground water availability and quality):</i> Kelkar et al., 2008
	Social	<i>Community Network and collective action:</i> Kuruppu, 2009
	Infrastructure	<i>Irrigation system:</i> Alcamo et al., 2007; Liu et al., 2008; Kelkar et al., 2008 <i>Access to drinking water:</i> Kelkar et al., 2008; Kuruppu, 2009 <i>Transportation (e.g. Road connection):</i> Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008 <i>Water Storage facilities:</i> Kelkar et al., 2008
	Individual knowledge	<i>Awareness based on past threats:</i> Kelkar et al., 2008; Kuruppu, 2009 <i>Level of education, literacy rate:</i> Acosta-Michlik and Espaldon, 2008; Liu et al., 2008; Kuruppu, 2009
	Governance	<i>Government social interventions (Conservation, watershed management, Water policy and government intervened pricing):</i> Acosta-Michlik and Espaldon, 2008; Lal et al., 2011

4.3.4 Forest sectors

Exposure Measure: Object of Vulnerability

Rising temperature and increasing run-off from increasing rainfall itself have been identified as a key factor affecting vulnerability in the forest sector (e.g. Lal et al., 2011; Rawlani and Sovacool, 2011). However, the unique exposure measure of the vulnerability studies other than commonly used measures such as climate variability or precipitation stems from the possibility of the pest and insect outbreak (i.e. Alig et al., 2004; Gan, 2004; Logan et al., 2003; Parkins and Mackendrick, 2007; Tschakert, 2007; Carina and Keskitalo, 2008; Kaushik and Khalid, 2011; Seidl et al., 2011; Perez-Garcia et al., 2002). In fact, damages to forest resources from pests can be significant (see Parkins and Mackendrick, 2007 for U.S. and Kaushik and Khalid, 2011 for India). For example, spruce bark beetle (*Dendroctonus rufipennis*) outbreaks in the Kenai Peninsula of Alaska (Berman et al. 1999) have led to the loss of over five million acres of Spruce forests. Parkins and Mackendrick (2007) suggest a basic framework for community level vulnerability assessment in the forest sector in Canada and considered the physical, social, political and economic dimensions of vulnerability to the outbreak of forest disease and incorporated a parsimonious set of 11 indicators derived from the published literature and the focus group sessions.

Also extreme event such as wild fire driven by climate change has been examined in the literature. In fact, in the U.S., warmer summer temperatures and reduced rainfall in the West are projected to extend the annual window of wildfire risk (Brown et al. 2004). Ruth et al. (2007) predict that due to the climate caused warming the state of Washington will face fire suppression cost increases of over 50% by 2020 and over 100% by 2040. Since many rural communities reside adjacent to forest or are dependent on forest industries for their livelihood, they tend to be directly impacted by these wildfires (Karnosky et al., 2005; Triggs et al., 2004).

Sensitivity Measure: Object of Vulnerability

Sensitivity of biodiversity has been examined in several studies. For example, Lal et al. (2011) show that the major concerns of interests are shifts in forest distribution and types, increased wildfire risk, increased chance of pest attacks and diseases, and adverse impacts on biodiversity.

More specifically, coastal region where mangrove forests constitute coastal wetlands is extremely vulnerable to sea level rise that has been driven by climate change. Moreover, mangroves in tropical region are extremely sensitive to global warming (Hay and Mimura, 2006; Kaushik and Khalid, 2011). However, mangroves can act as efficient shields against cyclonic waves, and their conservation is a must for any adaptation framework to be developed for coastal Orissa (Khalid et al., 2008).

Forest dependent communities are also used as a common unit of vulnerability analysis (i.e. Carina and Keskitalo, 2008; Fisher et al., 2010; Seidl et al., 2011). In particular, climate impact on forests may induce market incentives for intensive forest management such as planting, thinning, genetic conservation, tree improvement, and developing wood-conserving technologies. The climate effect on forest-dependent rural communities will vary depending on the geography, demographics, and social and economic conditions that each community faces. As in the case of agriculture, there are losers and winners. Higher levels of atmospheric CO₂ allow trees to capture more carbon from the atmosphere, resulting in higher growth rates in some regions, especially in relatively young forests on fertile soils (Ryan et al., 2008). The stimulating effect of growth depends on local conditions such as moisture stress and nutrient availability.

Adaptive capacity: Coping ability

The adaptive capacity in the rural community that has been identified as socio-economic component is mainly associated with forest resources (i.e. Parkins and Mackendrick, 2007; Fisher et al., 2010). For example, Fisher et al (2010) examine the role of forest product in Malawi that shares safety net characteristics of forest with other tropical countries. According to their studies, forest provides foods to the rural poor to survive famine, and is an important source of cash earnings when faced with weather-related crop failure. The study also finds that low income households who are located in proximity to forest, and are headed by individuals who are older, more risk averse, and less educated than their cohorts are particularly dependent on forests for coping with climatic shocks, probably because they have limited access to other coping mechanisms, such as asset sales.

Table 6. Local vulnerability measure in the forest sector

Exposure	<i>Precipitation:</i> Hay and Mimura, 2006; Seidl et al., 2011; Hughes, 2011	
	<i>Pest and insect outbreak:</i> Alig et al., 2004; Gan, 2004; Logan et al., 2003; Parkins and Mackendrick, 2007; Tschakert, 2007; Carina and Keskitalo, 2008; Kaushik and Khalid, 2011; Seidl et al., 2011	
	<i>Cyclones:</i> Hughes, 2011	
	<i>Climate rise:</i> Parkins and Mackendrick, 2007; Bernard and Ostlander, 2008; Lal et al., 2011	
	<i>Increase in dry season – wild fires:</i> Priceputu and Grepppin, 2006	
Sensitivity	Coastal area	<i>Mangrove forest:</i> Hay and Mimura, 2006; Hughes, 2011
	Forest dependent communities	<i>Forest product:</i> Carina and Keskitalo, 2008; Fisher et al., 2010; Seidl et al., 2011
Adaptive capacity	Economic	<i>Dependency on forestry (e.g. percent labor force income from all forest activities, demand for forest resource):</i> Parkins and Mackendrick, 2007; Carina and Keskitalo, 2008; Fisher et al., 2010; Seidl et al., 2011 <i>Housing location:</i> Bernard and Ostlander, 2008 <i>Flexibility of forest resource (e.g. percent non-pine tree species by area for Timber Harvesting Land Base):</i> Parkins and Mackendrick, 2007
	Individual knowledge	<i>Level of education , literacy rate:</i> Parkins and Mackendrick, 2007; Fisher et al., 2010
	Governance	<i>Government social interventions (e.g. insect control policy):</i> Carina and Keskitalo, 2008; Lal et al., 2011

4.3.5 Health Sector

Exposure Measure: Object of Vulnerability

It has been well known that as climate change continues, the frequency, intensity and duration of heat waves will increase, the distribution of mosquitoes and other insects will shift, sea level and ocean acidity will continue to rise and food production and water resources will be affected. In addition, global epidemiological reviews by Ahern et al. (2005) on floods and Shultz et al. (2005) on tropical cyclones identified potential disease associations with the extreme events.

Sensitivity Measure: Subject of Vulnerability

All these factors will have direct or indirect impacts on population health (e.g. Ebi et al., 2006; Smoyer, 1998). In fact one of the most complex and widespread impacts of climate hazards is harm on health. Climatic hazards produce both short-term and long-term health

risks either directly or indirectly including accident and injury and changes in exposure to vectors and pathogens, and psycho-social effects. Impacts on food supply chains and health care services are indirect and long-term (Ahern et al., 2005; Shultz et al., 2005).

Adaptive capacity: Coping ability

It has been pointed out that variables such as age, location, social connectedness, access to cultural, and economic resources are important determinants in the vulnerability assessment of climate change (Brondizio and Moran, 2008; Brouwer et al., 2007; Curriero et al., 2002). Interdependencies between natural systems (e.g. climate systems) and community health and well-being are likely to be significantly influenced by climate change (Strand et al., 2010; Ford et al., 2010). In this case, the following paragraphs describe some of the aspects of health hazards that need attention.

Temporal and geographical variations in weather and climate are harmful to the interaction between natural systems and health. Those variations lengthen the transmission season for vector-borne diseases in some areas and can be a significant threat to human health. For example, an increase in mean temperatures has been observed to increase the geographic distribution of mosquitoes and shorten the incubation period of the pathogen within the vector, which is likely to increase the risk of vector-borne diseases such as malaria, Dengue fever, Lyme disease, and Ross River Virus (Füssel and Klein, 2006; Strand et al., 2010; Lal et al., 2011; IDB-ECLAC, 2014a, 2014b).

Climate hazards on human health occur either directly (e.g., thermal stress) or indirectly (e.g., disease vectors and infectious agents) pathways. Direct impacts could result from increased exposure to temperature (heat waves, winter cold) and other extreme weather events (floods, cyclones, storm-surges, droughts) and increased production of air pollutants and aeroallergens such as spores and molds (Karl et al., 2009). Human health may also be indirectly impacted by an increase in water, food, and vector borne diseases.

Climate change-related impacts on health however, are more indirect and subtle. For example, climate change can negatively impact on food production, water quality and quantity, air quality, ecosystem functions (Soh et al., 2008; Tagaris et al., 2009; Diaz, 2007). For this reason, several local vulnerability case studies that focus on sectors have incorporated climate effect on health as one of primary component that builds local vulnerability index (e.g. Hay and Mumura, 2006; Füssel and Klein, 2006; Parkins and Mackendrick, 2007; Eriksen and Silva, 2009; Few and Tran, 2010; Yoo et al., 2011).

Few and Tran (2010) finds that as with most aspects of hazard impact in developing countries, economic factors are seen to have a fundamental role in health-related

vulnerability. They argue that income-poverty tended to constrain people's ability to prevent impacts, to seek treatment and to withstand disease. But poverty also operated in sometimes subtle, sometimes stark inter-linkage with other dimensions. The location of households most exposed to flood hazards, for example, is commonly alongside watercourses: in many cases the poorest families occupy marginal sites, sometimes illegally, and living in simple houses of fragile construction without raised foundations. Elderly population groups are especially vulnerable to the impacts of climate change (O'Brien et al., 2004; Strand et al., 2010).

National structures and access to primary health care (e.g. simple treatment, vaccinations, hygiene, commune health station and health education is important attribute of local vulnerability in health sector. Among the potential community adaptation strategies, community awareness, and partnerships between local government and small businesses are included (Strand et al., 2010). As in other sector studies, capability to avoid adverse health impacts depends on level of perception of climate change and its impact on health (Few and Tran, 2010).

Table 7. Local vulnerability measure in the health sectors

Exposure	<i>Increasing temperature:</i> Ford and Smit, 2004; Füssel and Klein, 2006; Diaz, 2007; Soh et al., 2008; Tagaris et al., 2009; Strand et al., 2010; Few and Tran, 2010; Lal et al., 2011	
Sensitivity	Human health	<i>Direct impact of climate on human health:</i> Few and Tran, 2010
	Health components in Agriculture, Coastal areas	<i>Vector borne disease indirectly caused by extreme weather events:</i> Mustafa, 1998; Hay and Mimura, 2006; Knutsson, and Ostwald, 2006; Tschakert, 2007; Hahn et al., 2009; Kuruppu, 2009; Rawlani and Sovacool, 2011; Yoo et al., 2011
Adaptive capacity	Population	<i>Elder population:</i> O'Brien et al., 2004; Strand et al., 2010
	Individual knowledge	<i>Awareness based on past threats:</i> Strand et al., 2010

5. Conclusions

Most of the attention on vulnerability index has been focused on the national level with some emphasis at the sector level. These more general indexes are useful when comparing at the country level, but lack usefulness for practitioners when going at the regional or local level. This paper presents systematized information from the relevant literature to examine the potential to develop a set of indicators that aggregates and convey information on the sector-specific climate impact and mitigating capacity at the local level.

The paper begins by examining limitations of global sector indices and critically evaluates previous efforts and achievements in measuring local vulnerability in each sector to draw several implications for the design of local vulnerability indexes. In particular, the paper applies a context-sensitive approach to vulnerability analysis and measurement, assessing the literature against each of the components of vulnerability, namely exposure, sensitivity and adaptive capacity. It reviews previous research on vulnerability assessment at the local-sector level for agriculture, coastal areas, water, forests and health. The paper provides systematized information to evaluate the possibility to devise indicators that can aggregate and convey sector-specific information at the local levels, expecting that such indicators can be candidate components of the sectoral index that can be applied systematically at the local level.

The paper finds that there can be common units of vulnerability analysis to measure exposure and sensitivity to climate impact across some sectors. The paper also finds that some variables/indicators can be adopted across different sectors even at the local level to be used as a proxy to measure each component of local vulnerability. For example, many studies adopt similarly quantified variables such as composition of wealth/income, communal governance, and age distribution of local population to measure adaptive capacity of local communities across many sectors.

It has been well acknowledged that given the imperfect data availability, selection of vulnerability indicators is likely to contain a subjective element. The paper emphasizes that aggregating indicators of exposure, sensitivity and adaptive capacity at the local level should not be generalized without due consideration, although some literature have proposed specific methodology of normalizing different proxies of indicators and creating digit number of aggregate local vulnerability index. The background information of the paper can be utilized for the choice of influential variables in the design of field studies for in-depth empirical research on vulnerability to climate change.

Finally, we should acknowledge that this is an incomplete review of the literature, given the nature of the subject and the increased interest in this area in the last years. It is worth noting that at the end of this literature survey, many new studies may have been published and that are not cited here.

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