Global Environmental Change 19 (2009) 74–88

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique

Micah B. Hahn [a,*], Anne M. Riederer [b], Stanley O. Foster [c]

[a] Global Environmental Health Program, Rollins School of Public Health, Emory University, 1518 Clifton Road, Atlanta, GA 30322, USA
[b] Department of Environmental and Occupational Health, Rollins School of Public Health, Emory University, 1518 Clifton Road, Atlanta, GA 30322, USA
[c] Hubert Department of Global Health, Rollins School of Public Health, Emory University, 1518 Clifton Road, Atlanta, GA 30322, USA

ARTICLE INFO

Article history:
Received 17 June 2008
Received in revised form 11 November 2008
Accepted 18 November 2008

Keywords:
Vulnerability
Index
Climate change
Adaptation
Sustainable development
Mozambique

ABSTRACT

We developed the Livelihood Vulnerability Index (LVI) to estimate climate change vulnerability in the Mabote and Moma Districts of Mozambique. We surveyed 200 households in each district to collect data on socio-demographics, livelihoods, social networks, health, food and water security, natural disasters and climate variability. Data were aggregated using a composite index and differential vulnerabilities were compared. Results suggest that Moma may be more vulnerable in terms of water resources while Mabote may be more vulnerable in terms of socio-demographic structure. This pragmatic approach may be used to monitor vulnerability, program resources for assistance, and/or evaluate potential program/policy effectiveness in data-scarce regions by introducing scenarios into the LVI model for baseline comparison.

1. Introduction

In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) states that "Africa is one of the most vulnerable continents to climate change and climate vulnerability," (2007a, p. 435) and that by the 2050s, 350–600 million Africans will be at risk for increased water stress, predominately in the northern and southern parts of the continent (Arnell, 2004; IPCC, 2007a). A composite of 23 climate models project that by the end of the century, annual median surface air temperature over the continent will increase by 3–4 °C (IPCC, 2007b). There is considerable variation in precipitation projections, and 90% of models are thought to overestimate rainfall in southern Africa (temperature biases in the models are not thought to be large enough to directly affect reliability of temperature projections); however, based on the 23-model composite, mean annual rainfall is expected to increase around 7% in tropical Africa and decrease in winter (June–August) up to 40% in southern Africa (IPCC, 2007a).

Climate change impacts are also are expected to disproportionately affect the poor, young, elderly, sick, and otherwise marginalized populations (Kasperson and Kasperson, 2001). Fields (2005) warns that the convergence of multiple stressors, including infectious disease, economic turbulence from globalization, resource privatization, and civil conflicts, combined with the lack of resources for adaptation, will present critical challenges for African communities struggling to adapt to climate change. Similarly, a dependence on agriculture and livestock and lack of irrigation means that African farmers are especially vulnerable to precipitation changes (Fields, 2005). These changes can result in over-farming, degradation of land resources, and increased pressure on wild game species and exposure to zoonotic diseases (Fields, 2005). Globally, climate policies of developed nations including increased reliance on biofuels may have a detrimental impact on staple food markets and consequently the nutrient needs of already malnourished populations (Boddiger, 2007). Further, expansion of biofuel crops may potentially encourage clear-cutting tropical rainforest, a critical carbon sink (Patz et al., 2007). These projections illustrate the concept of vulnerability to environmental change as "...an interactive phenomenon involving both nature and society, and particularly inequality and a lack of buffering against environmental threats" (Kasperson et al., 2001, p. 24). They emphasize the need to understand not just the climate science but to also place climate projections in the context of human societies, political systems, social hierarchies, and underlying health profiles in order to appreciate the complex network of issues that may arise in different populations as a result of climate change.

* Corresponding author. Present address: Center for Sustainability and the Global Environment, University of Wisconsin-Madison, 1710 University Avenue, Madison, WI 53726, USA. Tel.: +1 865 406 5929; fax: +1 608 265 4113.
E-mail addresses: mbhahn@wisc.edu (M.B. Hahn), arieder@sph.emory.edu (A.M. Riederer), sfoster@sph.emory.edu (S.O. Foster).

0959-3780/$ – see front matter
doi:10.1016/j.gloenvcha.2008.11.002

In addition to these broad-scale influences, local factors have also been shown to affect vulnerability at the household level. Eriksen et al. (2005) described how Kenyan and Tanzanian households where each member specializes in a limited number of intensive, cash-yielding coping strategies were generally less vulnerable than those whose members spread their time among several marginal livelihood activities. They also noted that many rural households lack the skills and access to capital needed to engage in the most desired, cash-yielding coping activities, and found that time availability, especially among women, was an important determinant of the ability to engage in favored coping strategies. This and other work further highlights the need to account for variability in social processes influencing vulnerability to climate change.

1.1. Climate change vulnerability assessment

Vulnerability assessment describes a diverse set of methods used to systematically integrate and examine interactions between humans and their physical and social surroundings. Vulnerability assessments have been used in a variety of contexts including the USAID Famine Early Warning System (FEWS-NET) (USAID, 2007a), the World Food Programme's Vulnerability Analysis and Mapping tool for targeting food aid (World Food Programme, 2007), and a variety of geographic analyses combining data on poverty, health status, biodiversity, and globalization (O'Brien et al., 2004; UNEP, 2004; Chen et al., 2006; Holt, 2007). A common thread is an attempt to quantify multidimensional issues using indicators as proxies. These are often combined into a composite index allowing diverse variables to be integrated. The Human Development Index, for example, incorporates life expectancy, health, education, and standard of living indicators for an overall picture of national well-being (UNDP, 2007). Several methods have been used to combine indicators. The gap method (Gillis et al., 1987) was used by Sullivan (2002, p. 1204) to assess "by how much water provision and use deviates from a predetermined standard" for the Water Poverty Index. Both the Human Development Index and the Water Poverty Index are examples of composite indices calculated using weighted averages of individual indicators. Weighting methods vary. Eakin and Bojorquez-Tapia (2008) note that equal weighting makes an implicit judgment about the degree of influence of each indicator and propose a complex fuzzy logic-based weighting method as a more objective approach. Vincent (2004, 2007) and Sullivan et al. (2002) suggest expert opinion and stakeholder discussion, respectively, to determine weighting schemes.

The field of climate vulnerability assessment has emerged to address the need to quantify how communities will adapt to changing environmental conditions. Various researchers have tried to bridge the gap between the social, natural, and physical sciences and contributed new methodologies that confront this challenge (Polsky et al., 2007). Many of these rely heavily on the IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity (IPCC, 2001). Exposure in this case is the magnitude and duration of the climate-related exposure such as a drought or change in precipitation, sensitivity is the degree to which the system is affected by the exposure, and adaptive capacity is the system's ability to withstand or recover from the exposure (Ebi et al., 2006).

Fussel and Klein (2006) divide available studies into first-generation vulnerability assessments based on climate impact assessments relative to baseline conditions, and second-generation assessments that incorporate adaptive capacity. Of the second-generation studies, there are a multitude of interpretations about how best to apply exposure, sensitivity, and adaptive capacity concepts to quantify vulnerability (Sullivan, 2002; O'Brien et al., 2004; Vincent, 2004; Ebi et al., 2006; Thornton et al., 2006; Polsky et al., 2007). Key differences among studies include scale, methods used to select, group, and aggregate indicators, and methods used to display results. There are also common limitations. Studies relying on climate scenario projections from General Circulation Models (GCMs) for example suffer from the uncertainty associated with these models and how results are mapped (O'Brien et al., 2004; Thornton et al., 2006). Studies relying on secondary data have to structure their analytical framework around available data, contend with inconsistent or missing data, and sometimes must combine data collected at different temporal or spatial scales (Sullivan et al., 2002; Vincent, 2004; Sullivan and Meigh, 2005). Information on sources of measurement error in secondary data sets is often lacking making sensitivity analysis difficult. Methods relying on sophisticated climate projections and multiple international and national databases may be impractical for health and development planners working at the community level.

1.2. The Livelihood Vulnerability Index

The Sustainable Livelihoods Approach, which looks at five types of household assets—natural, social, financial, physical, and human capital (Chambers and Conway, 1992), is an approach used to design development programming at the community level (United Nations General Assembly, 1997). The approach has proven useful for assessing the ability of households to withstand shocks such as epidemics or civil conflict. Climate change adds complexity to household livelihood security. The Sustainable Livelihoods Approach to a limited extent addresses the issues of sensitivity and adaptive capacity to climate change, but a new approach for vulnerability assessment that integrates climate exposures and accounts for household adaptation practices is needed in order to comprehensively evaluate livelihood risks resulting from climate change.

We combined previous methods to construct a Livelihood Vulnerability Index (LVI) to estimate the differential impacts of climate change on communities in two districts of Mozambique. This project was a collaborative effort between Emory University (Atlanta, GA, USA) and CARE-Mozambique (Maputo, Mozambique). The LVI uses multiple indicators to assess exposure to natural disasters and climate variability, social and economic characteristics of households that affect their adaptive capacity, and current health, food, and water resource characteristics that determine their sensitivity to climate change impacts. Two approaches are presented: the first expresses the LVI as a composite index comprised of seven major components while the second aggregates the seven into IPCC's three contributing factors to vulnerability—exposure, sensitivity, and adaptive capacity.

Our approach differs from previous methods in that it uses primary data from household surveys to construct the index. It also presents a framework for grouping and aggregating indicators on the district level, which can be critical for development and adaptation planning. By using primary household data, this approach helps avoid the pitfalls associated with using secondary data. Another advantage is the reduction in dependence on climate models, which despite recent advances are still presented at too large a scale to provide accurate projections at levels useful for community development planning (Patz et al., 2005; Sullivan, 2006). According to the IPCC (2007a, p. 443), "...very few regional to sub-regional climate change scenarios... or empirical downscaling have been constructed in Africa..." due largely to lack of climate data, human resources, and computational facilities. Within countries like Mozambique, with topography ranging from lowland coastal plains to highlands as well as varying levels of infrastructure and socio-economic development, regional climate projections likely mask differences in vulnerability between communities (Ehrhart and Twena, 2006). Rather than structuring this vulnerability assessment around climate projections, the LVI approach focuses on quantifying the strength of current livelihood and health systems as well as the capacity of communities to alter these strategies in response to climate-related exposures.

The LVI is designed to provide development organizations, policy makers, and public health practitioners with a practical tool to understand demographic, social, and health factors contributing to climate vulnerability at the district or community level. It is designed to be flexible so that development planners can refine and focus their analyses to suit the needs of each geographic area. In addition to the overall composite index, sectoral vulnerability scores can be segregated to identify potential areas for intervention.

2. Methods

2.1. Calculating the LVI: composite index approach

The LVI includes seven major components: Socio-Demographic Profile, Livelihood Strategies, Social Networks, Health, Food, Water, and Natural Disasters and Climate Variability. Each is comprised of several indicators or sub-components (Table 1). These were developed based on a review of the literature on each major component, for example studies on Mozambique's water sector, as well as the practicality of collecting the needed data through household surveys. Table 1 includes an explanation of how each sub-component was quantified, the survey question used to collect the data, the original source of the survey question, and potential sources of bias.

The LVI uses a balanced weighted average approach (Sullivan et al., 2002) where each sub-component contributes equally to the overall index even though each major component is comprised of a different number of sub-components. Because we intended to develop an assessment tool accessible to a diverse set of users in resource-poor settings, the LVI formula uses the simple approach of applying equal weights to all major components. This weighting scheme could be adjusted by future users as needed.

Because each of the sub-components is measured on a different scale, it was first necessary to standardize each as an index. The equation used for this conversion was adapted from that used in the Human Development Index to calculate the life expectancy index, which is the ratio of the difference of the actual life expectancy and a pre-selected minimum, and the range of pre-determined maximum and minimum life expectancy (UNDP, 2007):

$$index_{s_d} = \frac{s_d - s_{\min}}{s_{\max} - s_{\min}} \qquad (1)$$

where s_d is the original sub-component for district d, and $s_{\min}$ and $s_{\max}$ are the minimum and maximum values, respectively, for each sub-component determined using data from both districts. For example, the 'average time to travel to primary water source' sub-component ranged from 1 to 1470 min in the two districts we surveyed. These minimum and maximum values were used to transform this indicator into a standardized index so it could be integrated into the water component of the LVI. For variables that measure frequencies such as the 'percent of households reporting having heard about conflicts over water resources in their community,' the minimum value was set at 0 and the maximum at 100. Some sub-components such as the 'average agricultural livelihood diversity index' were created because an increase in the crude indicator, in this case, the number of livelihood activities undertaken by a household, was assumed to decrease vulnerability. In other words, we assumed that a household who farms and raises animals is less vulnerable than a household who only farms. By taking the inverse of the crude indicator, we created a number that assigns higher values to households with a lower number of livelihood activities. The maximum and minimum values were also transformed following this logic and Eq. (1) used to standardize these sub-components.

After each was standardized, the sub-components were averaged using Eq. (2) to calculate the value of each major component:

$$M_d = \frac{\sum_{i=1}^{n} index_{s_d i}}{n} \qquad (2)$$

where M_d = one of the seven major components for district d [Socio-Demographic Profile (SDP), Livelihood Strategies (LS), Social Networks (SN), Health (H), Food (F), Water (W), or Natural Disasters and Climate Variability (NDCV)], $index_{s_d i}$ represents the sub-components, indexed by i, that make up each major component, and n is the number of sub-components in each major component.

Once values for each of the seven major components for a district were calculated, they were averaged using Eq. (3) to obtain the district-level LVI:

$$\mathrm{LVI}_d = \frac{\sum_{i=1}^{7} w_{M_i} M_{di}}{\sum_{i=1}^{7} w_{M_i}} \qquad (3)$$

which can also be expressed as

$$\mathrm{LVI}_d = \frac{w_{SDP}SDP_d + w_{LS}LS_d + w_{SN}SN_d + w_H H_d + w_F F_d + w_W W_d + w_{NDC}NDCV_d}{w_{SDP} + w_{LS} + w_H + w_{SN} + w_F + w_W + w_{NDC}} \qquad (4)$$

where LVI_d, the Livelihood Vulnerability Index for district d, equals the weighted average of the seven major components. The weights of each major component, w_{Mi}, are determined by the number of sub-components that make up each major component and are included to ensure that all sub-components contribute equally to the overall LVI (Sullivan et al., 2002). In this study, the LVI is scaled from 0 (least vulnerable) to 0.5 (most vulnerable). For illustrative purposes, a detailed example of calculating the Food major component for the LVI for one of the Mozambican districts is presented in Appendix A.

2.2. Calculating the LVI–IPCC: IPCC framework approach

We developed an alternative method for calculating the LVI that incorporates the IPCC vulnerability definition. Table 2 shows the organization of the seven major components in the LVI–IPCC framework. Exposure of the study population is measured by the number of natural disasters that have occurred in the past 6 years, while climate variability is measured by the average standard deviation of the maximum and minimum monthly temperatures and monthly precipitation over a 6-year period. Adaptive capacity is quantified by the demographic profile of a district (e.g., percent of female-headed households), the types of livelihood strategies employed (e.g., predominately agricultural, or also collect natural resources to sell in the market), and the strength of social networks (e.g., percent of residents assisting neighbors with chores). Last, sensitivity is measured by assessing the current state of a district's food and water security and health status. The same sub-components outlined in Table 1 as well as Eqs. (1)–(3) were used to calculate the LVI–IPCC. The LVI–IPCC diverges from the LVI when the major components are combined. Rather than merge the major components into the LVI in one step, they are first combined according to the categorization scheme in Table 2 using the

Table 1
Major components and sub-components comprising the Livelihood Vulnerability Index (LVI) developed for two districts of Mozambique.

Major components	Sub-components	Explanation of sub-components	Survey question	Source	Potential limitations
Socio-demographic profile	Dependency ratio	Ratio of the population under 15 and over 65 years of age to the population between 19 and 64 years of age.	Could you please list the ages and sexes of every person who eats and sleeps in this house? If you had a visitor who ate and slept here for the last 3 days, please include them as well.	Adapted from Domestic Household Survey (DHS) (2006). Measure DHS: Model Questionnaire with Commentary	Large extended families; Confusion about who is a member of the household; Lack of birth certificates.
	Percent of female-headed households	Percentage of households where the primary adult is female. If a male head is away from the home >6 months per year the female is counted as the head of the household.	Are you the head of the household?	Adapted from DHS (2006)	Confusion regarding who is the head of the household when multiple families live together or husband is absent.
	Percent of households where head of household has not attended school	Percentage of households where the head of the household reports that they have attended 0 years of school.	Did you ever go to school?	Adapted from DHS (2006)	Confusion regarding who is the head of the household when multiple families live together or husband is absent.
	Percent of households with orphans	Percentage of households that have at least 1 orphan living in their home. Orphans are children <18 years old who have lost one or both parents.	Are there any children less than 18 years old from other families living in your house because one or both of their parents has died?	Adapted from DHS (2006)	Children of family members are sometimes not considered orphans and might not have been reported.
Livelihood	Percent of households with family member working in a different community	Percentage of households that report at least 1 family member who works outside of the community for their primary work activity.	How many people in your family go to a different community to work?	Adapted from World Bank (1997). Household Questionnaire: Survey of Living Conditions, Uttar Pradesh and Bihar	Confusion regarding who is a member of the family; Does not count members of the family who previously worked outside of community; Confusion about what is "outside of the community."
	Percent of households dependent solely on agriculture as a source of income	Percentage of households that report only agriculture as a source of income.	Do you or someone else in your household raise animals? Do you or someone else in your household grow crops? Do you or someone else in your household collect something from the bush, the forest, or lakes and rivers to sell?	Adapted from World Bank (1997)	Survey only asked about the three primary sources of income for families in the area.
	Average Agricultural Livelihood Diversification Index (range: 0.20–1)[a]	The inverse of (the number of agricultural livelihood activities +1) reported by a household, e.g., A household that farms, raises animals, and collects natural resources will have a Livelihood Diversification Index = 1/(3 + 1) = 0.25.	Same as above	Adapted from DHS (2006)	Survey only asked about the three primary sources of income for families in the area. Non-agricultural livelihoods such as mechanics, shopkeepers, etc. were not included.
Health	Average time to health facility (minutes)	Average time it takes the households to get to the nearest health facility.	How long does it take you to get to a health facility?	Adapted from World Bank (1997)	No watches; Subjective estimates of travel time.
	Percent of households with family member with chronic illness	Percentage of households that report at least 1 family member with chronic illness. Chronic illness was defined subjectively by respondent.	Is anybody in your family chronically ill (they get sick very often)?	Adapted from DHS (2006)	"Chronically ill" was subjectively defined by respondent.
	Percent of households where a family member had to miss work or school in the last 2 weeks due to illness	Percentage of households that report at least 1 family member who had to miss school of work due to illness in the last 2 weeks.	Has anyone in your family been so sick in the past 2 weeks that they had to miss work or school?	Adapted from World Heath Organization/Roll Back Malaria (2003). Determination of the Socio-economic Impacts of Malaria Epidemics in Africa.	Confusion regarding who is a member of the family; Recall bias (most severe episodes are mostly likely to be remembered).
	Average Malaria Exposure*Prevention Index (range: 0–12)	Months reported exposure to malaria*Owning at least one bednet indicator (have bednet = 0.5, no bednet = 1) (e.g., Respondent reported malaria is a problem January–March and they do not own a bednet = 3*1 = 3).	Which months of the year is malaria particularly bad? How many mosquito nets do you have?	Malaria: Adapted from WHO/RBM (2003). Bednets: DHS (2006)	Lack of calendars; Estimation of months by growing season; Reliance on self-reported number of bednets (no visual observation made); Recall bias (more likely to remember a malaria month if family member had malaria)

Table 1 (*Continued*)

Major components	Sub-components	Explanation of sub-components	Survey question	Source	Potential limitations
Social Networks	Average Receive:Give ratio (range: 0–15)	Ratio of (the number of types of help received by a household in the past month + 1) to (the number of types of help given by a household to someone else in the past month + 1).	In the past month, did relatives or friends help you and your family: (e.g., Get medical care or medicines, Sell animal products or other goods produced by family, Take care of children) In the past month, did you and your family help relatives or friends: (same choices as above)	Adapted from DHS (2006)	Confusion about who is family (immediate) and who is a relative (extended); Reliance on self-reported types of help/support.
	Average Borrow:Lend Money ratio (range: 0.5–2)	Ratio of a household borrowing money in the past month to a household lending money in the past month, e.g., If a household borrowed money but did not lend money, the ratio = 2:1 or 2 and if they lent money but did not borrow any, the ratio = 1:2 or 0.5.	Did you borrow any money from relatives or friends in the past month? Did you lend any money to relatives or friends in the past month?	Adapted from World Bank (1997)	Reliance on self-reported money exchanges; Does not consider exchange of non-monetary goods
	Percent of households that have not gone to their local government for assistance in the past 12 months	Percentage of households that reported that they have not asked their local government for any assistance in the past 12 months.	In the past 12 months, have you or someone in your family gone to your community leader for help?	Adapted from WHO/RBM (2003)	Reliance on self-reported visits to government; Recall bias (more likely to remember going to government for dire issues)
Food	Percent of households dependent on family farm for food	Percentage of households that get their food primarily from their personal farms.	Where does your family get most of its food?	Developed for the purposes of this questionnaire.	Subjective definition of “most”
	Average number of months households struggle to find food (range: 0–12)	Average number of months households struggle to obtain food for their family.	Does your family have adequate food the whole year, or are there times during the year that your family does not have enough food? How many months a year does your family have trouble getting enough food?	Adapted from World Bank (1997)	Subjective definition of “struggle”; Reliance on self-reported number of months; May not reflect the overall trend of food scarcity (respondents most likely to remember current year).
	Average Crop Diversity Index (range: >0–1)[a]	The inverse of (the number of crops grown by a household +1). e.g., A household that grows pumpkin, maize, nhemba beans, and cassava will have a Crop Diversity Index = 1/(4 + 1) = 0.20.	What kind of crops does your household grow?	Adapted from World Bank (1997)	No specification regarding the seasonality of crops.
	Percent of households that do not save crops	Percentage of households that do not save crops from each harvest.	Does your family save some of the crops you harvest to eat during a different time of year?	Developed for the purposes of this questionnaire.	Does not count families that sell crops and save money.
	Percent of households that do not save seeds	Percentage of households that do not have seeds from year to year.	Does your family save seeds to grow the next year?	Developed for the purposes of this questionnaire.	No specification regarding the year in question.

Water	Percent of households reporting water conflicts	Percentage of households that report having heard about conflicts over water in their community.	In the past year, have you heard about any conflicts over water in your community?	Developed for the purposes of this questionnaire.	Recall bias (more likely to remember violent conflicts)
	Percent of households that utilize a natural water source	Percentage of households that report a creek, river, lake, pool, or hole as their primary water source.	Where do you collect your water from?	Adapted from DHS (2006)	Confusion when families have multiple water sources.
	Average time to water source (minutes)	Average time it takes the households to travel to their primary water source.	How long does it take to get to your water source?	Adapted from DHS (2006)	No watches; Subjective estimates of travel time; Different family members collect water.
	Percent of households that do not have a consistent water supply	Percentage of households that report that water is not available at their primary water source everyday	Is this water available everyday?	Adapted from World Bank (1997)	Recall bias (more likely to remember several consecutive days of water shortage)
	Inverse of the average number of liters of water stored per household (range: >0–1)	The inverse of (the average number of liters of water stored by each household + 1).	What containers do you usually store water in? How many? How many liters are they?	Developed for the purposes of this questionnaire.	Lack of information about size of containers
Natural disasters and climate variability	Average number of flood, drought, and cyclone events in the past 6 years (range: 0–7)	Total number of floods, droughts, and cyclones that were reported by households in the past 6 years.	How many times has this area been affected by a flood/cyclone/drought in 2001–2007?	Adapted from Williamsburg Emergency Mngmnt (2004). Household Natural Hazards Preparedness Questionnaire.	Recall bias (most severe disasters are most likely to be remembered)
	Percent of households that did not receive a warning about the pending natural disasters	Percentage of households that did not receive a warning about the most severe flood, drought, and cyclone event in the past 6 years.	Did you receive a warning about the flood/cyclone/drought before it happened?	Adapted from Williamsburg Emergency Mngmnt (2004)	Subjective definition of "warning."
	Percent of households with an injury or death as a result of the most severe natural disaster in the past 6 years	Percentage of households that reported either an injury to or death of one of their family members as a result of the most severe flood, drought, or cyclone in the past 6 years.	Was anyone in your family injured in the flood/cyclone drought? Did anyone in your family die during the flood/cyclone/drought?	Developed for the purposes of this questionnaire.	Recall bias (severe injuries are most likely to be remembered)
	Mean standard deviation of the daily average maximum temperature by month	Standard deviation of the average daily maximum temperature by month between 1998 and 2003 was averaged for each province[b]	1998–2003: provincial data; weather station based in the provincial capital	Instituto Nacional de Estatistica (2007)	Reliance on average data; Short time period.
	Mean standard deviation of the daily average minimum temperature by month	Standard deviation of the average daily minimum temperature by month between 1998 and 2003 was averaged for each province.	1998–2003: provincial data; weather station based in the provincial capital	Instituto Nacional de Estatistica (2007)	Reliance on average data; Short time period.
	Mean standard deviation of average precipitation by month	Standard deviation of the average monthly precipitation between 1998 and 2003 was averaged for each province	1998–2003: provincial data; weather station based in the provincial capital	Instituto Nacional de Estatistica (2007)	Reliance on average data; Short time period.

[a] Some indicators such as the Livelihood Diversity Index were created because an increase in the crude indicator, in this case, the number of livelihood activities undertaken by a household, decreases vulnerability (e.g., a household who farms and raises animals is less vulnerable than a household who only farms) so by taking the inverse of the crude indicator, we create a number that reflects this line of reasoning and assigns higher values to households with a lower number of livelihood activities.

[b] Provinces are the primary administrative unit and districts are the secondary administrative unit in Mozambique.

Table 2
Categorization of major components into contributing factors from the IPCC (Intergovernmental Panel on Climate Change) vulnerability definition for calculation of the LVI–IPCC.

IPCC contributing factors to vulnerability	Major components
Exposure	Natural disasters and climate variability
Adaptive capacity	Socio-demographic profile Livelihood strategies Social networks
Sensitivity	Health Food Water

following equation:

$$CF_d = \frac{\sum_{i=1}^{n} w_{M_i} M_{di}}{\sum_{i=1}^{n} w_{M_i}} \quad (5)$$

where CF_d is an IPCC-defined contributing factor (exposure, sensitivity, or adaptive capacity) for district d, M_{di} are the major components for district d indexed by i, w_{Mi} is the weight of each major component, and n is the number of major components in each contributing factor. Once exposure, sensitivity, and adaptive capacity were calculated, the three contributing factors were combined using the following equation:

$$LVI - IPCC_d = (e_d - a_d) * s_d$$

where $LVI–IPCC_d$ is the LVI for district d expressed using the IPCC vulnerability framework, e is the calculated exposure score for district d (equivalent to the Natural Disaster and Climate Variability major component), a is the calculated adaptive capacity score for district d (weighted average of the Socio-Demographic, Livelihood Strategies, and Social Networks major components), and s is the calculated sensitivity score for district d (weighted average of the Heath, Food, and Water major components). We scaled the LVI–IPCC from −1 (least vulnerable) to 1 (most vulnerable). For illustrative purposes, a detailed example of calculating the contributing factors of the LVI–IPCC for one of the two Mozambican districts is presented in Appendix B.

2.3. Study area

We pilot tested the LVI and LVI–IPCC in the Moma and Mabote Districts of Mozambique during 2007. These were selected by CARE-Mozambique as representative of coastal and inland communities, respectively, and the climate change issues confronting each. Additionally, CARE had worked previously in these districts and therefore has established relationships with the local government and communities. The illiteracy rate in Moma is 85% (males: 74.8%, females: 94.9%) and in Mabote, 81.4% (males: 73.3%, females: 81.4%) compared to 60.5% nationally (males: 44.6%, females: 74.1%) (Government of Mozambique, 2007). Moma is located in Nampula Province, northern Mozambique with a land area of 5752 km^2 (Government of Mozambique, 2005b) and a population of 329,181 (Government of Mozambique, 2007). Mabote is located in eastern Inhambane Province with a land area of 14,577 km^2 and a population of 45,000 (Government of Mozambique, 2005a). Average annual rainfall in Moma is approximately 800–1000 mm with over 90% of the precipitation falling between November and April (Government of Mozambique, 2005b). The 600 annual mm of rain in Mabote follows a similar seasonal pattern (Government of Mozambique, 2005a). The average temperature in both districts is approximately 24 °C, ranging from 13 to 31 °C throughout the year (Government of Mozambique, 2005a,b). In addition to the projected changes in temperature and winter rainfall discussed above, regional climate projections predict an increase in rainfall intensity coupled with a decrease in number of rain days in southern Africa (Tadross et al., 2005). Since 1970, Mozambique has been impacted by 48 natural disasters (EM-DAT, 2007) including the 2000–2001 flooding that killed 700 people and affected 2 million nationwide (National Institute of Disaster Management (INGC) et al., 2003) and Cyclone Favio in February 2007 that affected over 162,000 people in Inhambane Province (USAID, 2007b). In Mabote, 91% of people engage in agriculture for their primary livelihood activity while in Moma many supplement farming activities with fishing (Government of Mozambique, 2007). Thus in addition to physical destruction, cyclones, floods, and droughts have the potential to leave local families without the means to generate income. Negative impacts of the 2000–2001 floods for example were intensified as a result of the high dependence on agriculture, high levels of poverty, large national debt, and lack of proper dam infrastructure and emergency preparedness planning (Mirza, 2003).

2.4. Household surveys

Based on a sample size calculation (WHO, 2005) at the 95% confidence interval, ±10% precision, 50% prevalence,[1] and a design effect of 2 to account for cluster sampling, 200 households in each district were surveyed.[2] National 1997 census data that specified the total population in each village was used to select 20 villages in each district using the probability proportional to size method (WHO, 2005; UNICEF, 2008). Interviews were conducted by field staff from CARE-Mozambique. Once the field team arrived in the village, community leaders were consulted to explain the purpose of the study and obtain permission to visit households. The household sampling method was adapted from the World Health Organization (WHO)'s Expanded Program on Immunization "random walk" methodology (WHO, 2005). Briefly, the team stood in the center of the village and spun a pencil in the air to randomly select a starting direction for the first interviewer (UNICEF, 2008). The other two interviewers turned to face at 120° angles from the first. A random number was selected from a dollar bill, and the interviewers walked in their respective directions, counting houses until they reached the selected number. This was the first house to be interviewed. Interviewers continued on their respective paths, moving to the next closest house until they had interviewed their quota for the village. If a household on the path was empty when the interviewer knocked on the door, s/he skipped that household and moved to the next closest household. The interviewers returned to any empty households to see if the habitants had returned and would agree to be interviewed. If the household was still empty when the interviewer returned, then they went back to the last household they interviewed and resumed interviewing at the next house on the original path. Ten households were interviewed in each village. Verbal consent was obtained from each head of household. The original protocol stated that interviews would be conducted only with women. The field team found that often men would answer for the wife when she was asked questions or that the woman was hesitant to answer in the presence of her husband. In order to expedite interviewing and create a more comfortable environment for the respondents, the male or female head of household was interviewed. Identifying information recorded was limited to the name of the village and the questionnaire number. Surveys were conducted with the approval of the Emory University human subjects research ethics board.

[1] 50% prevalence refers to the point prevalence of the indicators selected for the LVI. This is the default value for sample size calculations when the prevalence of the indicators is unknown.

[2] Sample size formula: $N = DEFF^*[(Z^{2*}p^*q)/e^2]$, where N = sample size, DEFF = 2; Z = 1.96 (95% CI), p = 0.5; q = 0.5; e = 0.10.

Table 3
Livelihood Vulnerability Index (LVI) sub-component values and minimum and maximum sub-component values for Moma and Mabote Districts, Mozambique.

Major component	Sub-component	Units	Moma	Mabote	Maximum value in both districts	Minimum value in both districts
Socio-demographic profile	Dependency ratio	Ratio	1.13	0.99	12.0	0
	Percent of female-headed households	Percent	14	84	100	0
	Average age of female head of household	1/Years	0.017	0.022	0.05	0.01
	Percent of households where head of household has not attended school	Percent	36.6	64	100	0
	Percent of households with orphans	Percent	13	22.5	100	0
Livelihood strategies	Percent of households with family member working in a different community	Percent	21.5	62	100	0
	Percent of households dependent solely on agriculture as a source of income	Percent	31.2	12.1	100	0
	Average agricultural livelihood diversification index	1/# livelihoods	0.37	0.32	1	0.2
Social networks	Average receive:give ratio	Ratio	1.19	1.33	8	0.3
	Average borrow:lend money ratio	Ratio	1.01	1.03	2	0.5
	Percent of households that have not gone to their local government for assistance in the past 12 months	Percent	92	95.5	100	0
Health	Average time to health facility	Minutes	189.1	593.3	4320	1
	Percent of households with family member with chronic illness	Percent	36	44.5	100	0
	Percent of households where a family member had to miss work or school in the last 2 weeks due to illness	Percent	60.3	14.5	100	0
	Average malaria exposure*prevention index	Months*Bednet Indicator	3.12	2.85	12	0
Food	Percent of households dependent solely on family farm for food	Percent	97.5	87	100	0
	Average number of months households struggle to find food	Months	3.8[a]	8.8	12	0
	Average crop diversity index	1/# crops	0.27	0.22	1	0.1
	Percent of households that do not save crops	Percent	26.5	3.5	100	0
	Percent of households that do not save seeds	Percent	8.5	4.5	100	0
Water	Percent of households reporting water conflicts	Percent	95	37.7	100	0
	Percent of households that utilize a natural water source	Percent	37	0.5	100	0
	Average time to water source	Minutes	55.6	16.8	360	1
	Percent of households that do not have a consistent water supply	Percent	36	6	100	0
	Inverse of the average number of liters of water stored per household	1/Liters	0.020	0.008	1	0.0007
Natural disasters and climate variability	Average number of flood, drought, and cyclone events in the past 6 years	Count	5.2	4.9	11	0
	Percent of households that did not receive a warning about the pending natural disasters	Percent	63.6[b]	62.3	100	0
	Percent of households with an injury or death as a result of recent natural disasters	Percent	4.5	0.5	100	0
	Mean standard deviation of monthly average of average maximum daily temperature (years: 1998–2003)	Celsius	0.8	1.4	1.9	0.4
	Mean standard deviation of monthly average of average minimum daily temperature (years: 1998–2003)	Millimeters	0.8	1.4	3.1	0.3
	Mean standard deviation of monthly average precipitation (years: 1998–2003)	Millimeters	60.6	76.2	247.8	4.5

[a] The missing response rate for this question was significantly different for Moma (41.5%) and Mabote (6.5%) districts (Fisher's Exact <0.001). The missing response rates for all other questions was less than 5%.

[b] The missing response rate for this question was significantly different for Moma (14.5%) and Mabote ($<1\%$) districts (Fisher's Exact <0.001). The missing response rates for all other questions was less than 5%.

Surveys consisted of nine sections: Household Demographic Information, Occupation and Water Management Practices, Social Networks, Community-Identified Problems Assessment, Access to Health Services and Health Assessment, Food Security, Water Stress, Natural Disasters, and Vector-Borne Disease. Survey questions are listed in Table 1. Each interview lasted on average 30 min. Surveys were carried out in Portuguese, Xitswa, and Makua depending on the primary language of the household head. Interviewers were native speakers of both Portuguese and either Xitswa or Makua and all were trained on the sample design, survey technique, and confidentiality protocol. Internal quality control procedures were established during training. For example, where survey questions contained ambiguous language that might lead to different answers depending on respondent interpretation, all field staff agreed upon a common definition. Generally the head of the household was interviewed, but if s/he was not available, the spouse was interviewed. Data were coded and cleaned using EpiInfo (CDC, Atlanta, Georgia, USA), and data analysis was carried out using SAS v9.1 (SAS Institute, Cary, North Carolina).

3. Results

All but one eligible household agreed to participate in the survey. The frequency of missing responses ranged from 0 to 5% for most survey questions, and there was no significant difference between Moma and Mabote districts in missing response rates for these questions (Fisher's Exact >0.05). The frequency of missing data for the average number of months a household struggles to find food was significantly different for Moma (41.5%) and Mabote (6.5%) districts (Fisher's Exact <0.001). Also, the frequency of missing responses for received warning before the most recent natural disaster event was significantly different for Moma (14.5%) and Mabote (<1%) districts (Fisher's Exact <0.001).

3.1. LVI: Moma versus Mabote

Table 3 presents the LVI sub-component values for each district as well as the minimum and maximum values for both combined. The major components and the composite LVI for each district are presented in Table 4. The dependency ratio index was higher for Moma (0.094) than Mabote (0.083). Overall however, Mabote showed greater vulnerability on the Socio-Demographic Profile index than Moma (SDP_{Moma} 0.175; SDP_{Mabote} 0.411). Mabote respondents reported a higher proportion of young, female-headed households and a smaller proportion of household heads that attended school than Moma respondents (The proportion of female-headed households in this study was 84% in Mabote compared to the national average of approximately 30% in the 1997 census (Nhacolo et al., 2006)). Often female respondents listed their husband as the head of the household but when questioned further, explained that he lived away from the house for more than 6 months per year. In these cases, the female respondent was coded as the head of the household. The average reported age of Moma female household heads was 59.4 $\pm$ 24.3 years versus 46.2 $\pm$ 18.0 years in Mabote. Over 22% of Mabote households reported raising an orphan while of these 53.3% reported raising more than one (not shown); in Moma, the proportions were 13% and 32%, respectively.

Mabote also showed greater vulnerability on the Livelihood Strategies component (0.297) than Moma (0.246). A higher percentage of Moma households reported relying solely on agriculture for income (agriculture dependency index: Moma 0.312, Mabote 0.121). Further, Mabote households on average reported employing 2.4 $\pm$ 0.9 livelihood strategies versus 1.9 $\pm$ 0.8 reported by Moma households. This is reflected in the livelihood diversification indices: Moma 0.213, Mabote 0.150. These strategies include growing crops, raising animals, and collecting natural resources (Table 1). On average, household heads in both Moma and Mabote reported farming for 21.7 $\pm$ 14.4 years, raising animals for 6.8 $\pm$ 7.0 years, and collecting natural resources for 6.8 $\pm$ 11.1 years as ways to cope with variable precipitation. Although Moma had higher vulnerability scores for two of the Livelihood Strategies indicators, more Mabote households reported having family members who travel outside the community to work (different community index: Moma 0.215, Mabote 0.620). When the three sub-components were averaged, the overall Livelihood Strategies vulnerability score was higher for Mabote than Moma.

The Social Networks indicators were similar for the two districts. Over 95% of Mabote and 92% of Moma households said they had not approached their local government for assistance in the past month. Mabote households reported borrowing money more frequently and receiving more in-kind assistance from family and friends relative to the number of times they lent money or provided assistance in the past month than Moma households (borrow:lend ratio: Moma 0.340, Mabote 0.353; receive:give ratio: Moma 0.013, Mabote 0.076). Overall, Mabote households were more vulnerable than Moma households on the Social Networks component (0.480 versus 0.457, respectively).

Moma households reported traveling an average of 189.1 $\pm$ 176.6 min to a health facility while Mabote households reported an average of 593.3 $\pm$ 1130.4 min. Chronic illness was reported by 36% of households in Moma compared to 44.5% in Mabote. 60.3% of Moma households said that a family member missed work due to illness in the past 2 weeks compared to 14.5% of Mabote households. Moma households also reported being more vulnerable to malaria than Mabote households (malaria prevention*exposure index: Moma 0.260, Mabote 0.238). When the sub-components were combined, the overall Health vulnerability score for Moma (0.317) was higher than that for Mabote (0.241).

Mabote households reported struggling to find adequate food for their families 8.8 $\pm$ 3.5 months per year on average compared to 3.8 $\pm$ 2.3 months in Moma. These results should be interpreted with caution however because of the large fraction of missing responses to this question among Moma respondents. A smaller percentage of Mabote households (87.0%) reported relying solely on their farm for food compared to 97.5% of Moma households, while Mabote households reported growing 4.3 $\pm$ 1.4 types of crops on average compared to 3.2 $\pm$ 1.4 by Moma households. A higher proportion of Mabote than Moma households reported storing crops and saving seeds (store crops index: Moma 0.265, Mabote 0.035; save seeds index: Moma 0.085, Mabote 0.045). The overall Food vulnerability score for Mabote was lower (0.361) than that for Moma (0.364).

Mabote also had a lower vulnerability score (0.099) for the Water component than Moma (0.370). In Moma, 37% of households reported using a natural water source while more than 99% of households in Mabote reported getting water from a community pump. Moma households reported storing 48.5 $\pm$ 28.1 L of water on average compared to 132.0 $\pm$ 145.8 L in Mabote. As a result, 94% of households in Mabote have a consistent water supply while only 64% of Moma households have water every day. Similarly, Mabote households reported traveling 16.8 $\pm$ 25.7 min on average to get water compared to 55.5 $\pm$ 60.7 min in Moma. 37.7% of Mabote households reported hearing about conflicts over water in their communities compared to 95% of Moma households.

Both districts had similar Natural Disaster vulnerability scores, based on the average reported number of flood, drought, and cyclone events the past 6 years, the percent of households who said they received no warning, and the percent of households reporting a disaster-related injury or death. These results should be interpreted with caution however because the proportion of missing responses to this question differed significantly between Moma and Mabote respondents. When climate variability was integrated into Natural Disaster index however, Mabote households were more vulnerable (0.409) than Moma (0.312) households.

Overall, Mabote had a higher LVI than Moma (0.326 versus 0.316, respectively), indicating relatively greater vulnerability to climate change impacts. The results of the major component calculations are presented collectively in a spider diagram (Fig. 1). The scale of the diagram ranges from 0 (less vulnerable) at the center of the web, increasing to 0.5 (more vulnerable) at the outside edge in 0.1 unit increments. Fig. 1 shows that Mabote is more vulnerable in terms of socio-demographic profile, while Moma is more vulnerable in terms of water resources and health profile.

Table 4
Indexed sub-components, major components, and overall LVI for Moma and Mabote Districts, Mozambique.

Sub-component	Moma	Mabote	Major component	Moma	Mabote
Dependency ratio	0.094	0.083	Socio-demographic profile	0.175	0.411
Percent of female-headed households	0.140	0.840			
Average age of female head of household	0.144	0.269			
Percent of households where head of household has not attended school	0.366	0.640			
Percent of households with orphans	0.130	0.225			
Percent of households with family member working in a different community	0.215	0.620	Livelihood strategies	0.246	0.297
Percent of households dependent solely on agriculture as a source of income	0.312	0.121			
Average agricultural Livelihood Diversification Index	0.213	0.150			
Average Receive:Give ratio	0.013	0.076	Social networks	0.457	0.480
Average Borrow:Lend Money ratio	0.340	0.353			
Percent of households that have not gone to their local government for assistance in the past 12 months	0.920	0.955			
Average time to health facility	0.044	0.137	Health	0.317	0.241
Percent of households with family member with chronic illness	0.360	0.445			
Percent of households where a family member had to miss work or school in the last 2 weeks due to illness	0.603	0.145			
Average Malaria Exposure*Prevention Index	0.260	0.238			
Percent of households dependent solely on family farm for food	0.975	0.870	Food	0.364	0.361
Average number of months households struggle to find food	0.313[a]	0.732			
Average Crop Diversity Index	0.180	0.124			
Percent of households that do not save crops	0.265	0.035			
Percent of households that do not save seeds	0.085	0.045			
Percent of households reporting water conflicts	0.950	0.377	Water	0.370	0.099
Percent of households that utilize a natural water source	0.370	0.005			
Average time to water source	0.152	0.044			
Percent of households that do not have a consistent water supply	0.360	0.060			
Inverse of the average number of liters of water stored per household	0.020	0.007			
Average number of flood, drought, and cyclone events in the past 6 years	0.475	0.447	Natural disasters and climate variability	0.312	0.409
Percent of households that did not receive a warning about the pending natural disasters	0.637[b]	0.623			
Percent of households with an injury or death as a result of recent natural disasters	0.045	0.005			
Mean standard deviation of monthly average of average maximum daily temperature (years: 1998–2003)	0.295	0.690			
Mean standard deviation of monthly average of average minimum daily temperature (years: 1998–2003)	0.189	0.395			
Mean standard deviation of monthly average precipitation (years: 1998–2003)	0.231	0.295			
Overall LVI					
LVI: Moma 0.316					
LVI: Mabote 0.326					

Index values should be interpreted as relative values to be compared within the study sample only. The LVI is on a scale from 0 (least vulnerable) to 0.5 (most vulnerable).

[a] The missing response rate for this question was significantly different for Moma (41.5%) and Mabote (6.5%) districts (Fisher's Exact <0.001). The missing response rates for all other questions was less than 5%.

[b] The missing response rate for this question was significantly different for Moma (14.5%) and Mabote (<1%) districts (Fisher's Exact <0.001). The missing response rates for all other questions was less than 5%.

3.2. LVI–IPCC: Moma versus Mabote

The LVI–IPCC analysis yielded similar results (LVI–IPCC: Moma −0.074, Mabote 0.005) (Table 5). Fig. 2 shows a vulnerability triangle, which plots the contributing factor scores for exposure, adaptive capacity, and sensitivity. The triangle illustrates that Mabote may be more exposed (0.409) to climate change impacts than Moma (0.312). However, accounting for the current health status as well as food and water security, Moma may be more sensitive to climate change impacts than Mabote (0.353 versus 0.233, respectively). Based on demographics, livelihoods, and social networks, Moma showed a higher adaptive capacity (0.522 versus 0.388 for Mabote). The overall LVI–IPCC scores indicate that Mabote households may be more vulnerable than Moma households (0.005 versus −0.074, respectively).

4. Discussion

4.1. Practical implications of the Moma versus Mabote LVI comparison

The major vulnerability components presented in Fig. 1 provide information on which household characteristics contribute most to climate change vulnerability in each district. These in turn might be programmed for community assistance. For example, although southern Mozambique suffers from recurrent drought (Govern-

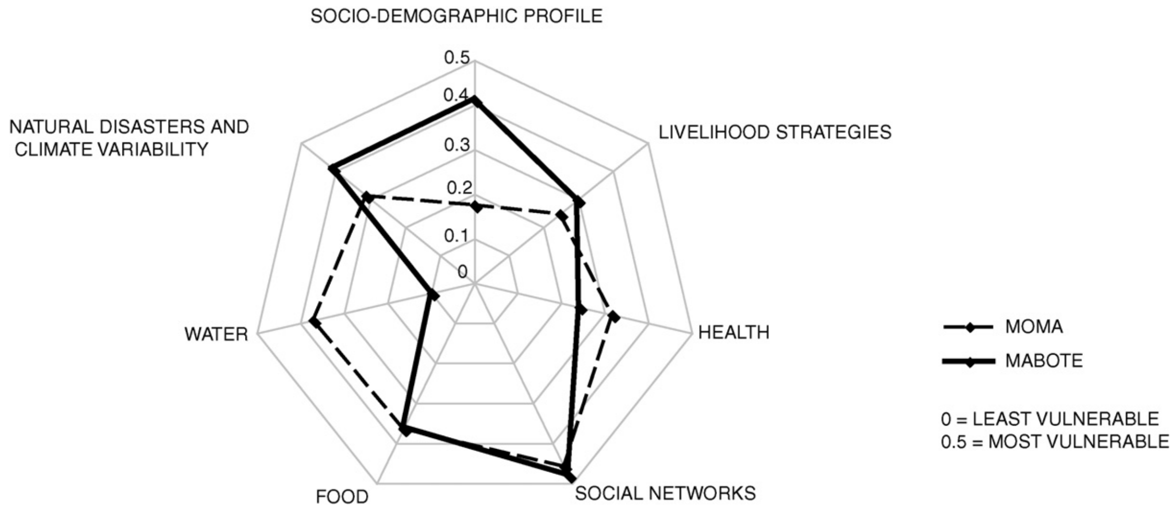

Fig. 1. Vulnerability spider diagram of the major components of the Livelihood Vulnerability Index (LVI) for Moma and Mabote Districts, Mozambique.

ment of Mozambique, 2005a), the field team observed that many Mabote households have adapted by installing 210 L plastic water storage containers. Similarly, the field teams noted boreholes installed throughout the Mabote communities they visited. This might help explain the shorter time that Mabote households reported traveling to a water source. These water management practices have likely decreased the vulnerability of the water sector in Mabote and are reflected in its low Water vulnerability score despite drought conditions. This suggests that resources that may have been spent on water assistance in a drought-prone area might be reallocated to a more vulnerable sector.

Similarly, although Mabote households reported struggling to find food almost 5 months longer per year than Moma households, a higher proportion of Mabote households reported engaging in seed storage and other food management practices. As a result, although Moma households did not report the same level of food insecurity as drought-stricken Mabote households, the Moma households had a higher vulnerability score. This suggests that education on food storage, crop diversification, and seed preservation might constitute an appropriate intervention for Moma households despite their current secure food status relative to Mabote households. The fact that the two districts had significantly different missing response rates on the number of months a household struggles to find food question may signify selection bias that would influence the comparison however. In Moma, this question had a high missing response rate. When field staffs were queried, they noted that the question was easy to skip by accident because of its placement on the page. Thus it is likely that the missing responses resulted from interviewer error rather than selection bias.

Mabote households also reported diversifying their income sources beyond farming by collecting natural resources to sell in the market and raising livestock such as pigs, goats, chickens, and in a few cases, cows. Despite these practices, Mabote was more vulnerable than Moma in terms of the Livelihood Strategies index. Another coping strategy used by Mabote families is to send their sons and husbands outside the community to work (Nhacolo et al., 2006). Although this migration may fill immediate income needs, historically this practice exacerbated the HIV/AIDS epidemic in Mozambique and South Africa (Clark et al., 2007; Hosegood et al., 2007). This widely studied phenomenon was the rationale for assigning higher vulnerability scores to households reporting family members working outside the community. Future researchers might include quantitative estimates of yearly household income and expenditures instead of this more indirect measure of livelihood stability.

Although Mabote households reported a longer average time to health facilities and a higher prevalence of chronic illness, Moma households reported longer periods of malaria and lower rates of bednet ownership. The high percent of people who were so sick in the past 2 weeks that they had to miss work in Moma compared to the percent in Mabote could be an artefact of the large percent of working age men who are living outside of the Mabote communities, leaving predominately non-working family members at home. These findings suggest that diseases like malaria may have a negative impact on household income by limiting the number of healthy work days. Based on these findings, targeted bednet distribution and a follow-up health assessment to determine the diseases causing people to miss work might be advisable for Moma. Further analysis of location and quality of health facilities in Mabote might help uncover reasons why Mabote households reported long traveling times to seek health care.

The borrow money:lend money and receive assistance:give assistance ratios were created to measure the degree to which households rely on family and friends for financial assistance and in-kind help. We assumed that a household that receives money or in-kind assistance often but offers little assistance to others is more insecure and vulnerable compared to those with excess money and time to help others. The finding that Mabote households had higher borrow:lend and receive:give ratios may be related to the higher proportion of female-headed households in that district. Also, the field team noted that the familial structure in Mabote consisted of large compounds with multiple houses for extended family while in Moma, houses were separated by immediate family. These living arrangements may have influenced the way residents judged help versus obligation, but we did not measure

Table 5
LVI–IPCC contributing factors calculation for Moma and Mabote Districts, Mozambique (IPCC, 2001).

IPCC contributing factors to vulnerability	Moma	Mabote
Exposure	0.312	0.409
Adaptive capacity	0.522	0.388
Sensitivity	0.353	0.233
LVI–IPCC	−0.074	0.005

Index values should be interpreted as relative values to be compared within the study sample only. The LVI–IPCC is on a scale from −1 (least vulnerable) to 1 (most vulnerable).

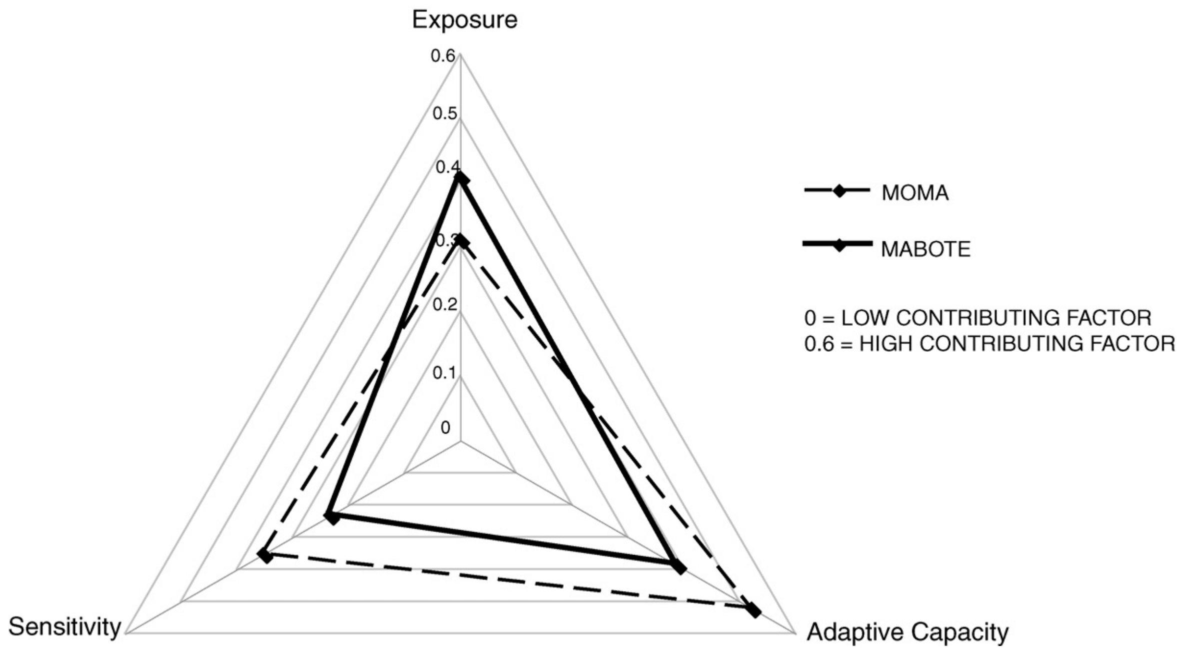

Fig. 2. Vulnerability triangle diagram of the contributing factors of the Livelihood Vulnerability Index-IPCC (LVI–IPCC) for Moma and Mabote Districts, Mozambique.

this directly. Community bonds and high levels of trust among households are important for decreasing vulnerability to climate change impacts (Thomas et al., 2005), however these social characteristics can be more difficult to measure than food security and health indicators. Although the Social Networks index did not contribute much to the LVI of either district, this could be because the indicators we used did not accurately reflect local social customs. This might be further investigated through focus groups held to discuss the structure of social networks in each district or by measuring households' perceived strength of their social networks (e.g., by asking respondents to draw a circle with spokes indicating each person they could ask for help in an emergency). Other measures of social capital include a household's range of contacts/access to formal government structures, access to information and agricultural technical support (Eakin and Bojorquez-Tapia, 2008), degree of gender equity (O'Brien et al., 2004), as well as the number of social groups to which a household belongs (Vincent, 2007). Despite the challenges in quantifying social networks, their inclusion in climate vulnerability assessments is essential as many adaptation behaviors rely on collective insurance mechanisms such as agricultural cooperatives.

Finally, although Moma households reported a higher absolute number of natural disasters over the past 6 years, the variability in the monthly average minimum and maximum daily temperature and precipitation has been greater in southern Mozambique, resulting in a higher NDCV score for Mabote. Early warning systems and community preparedness plans may help communities in both districts prepare for extreme weather events. Seasonal weather forecasts distributed through local farming associations may help farmers time their plantings and prevent diversion of scarce water resources for irrigation. We chose 6 years as the recall window for the natural disaster indicator because we thought that respondents would not accurately report disasters earlier than that (Fowler, 2002). This question may have been subject to recall bias if households that were less able to withstand the impacts of a natural disaster were more likely to report the occurrence of these events. A natural disaster database would be a more accurate indicator of natural disaster exposure if it were available at the district level. Incorporation of data on the duration and severity of natural disasters may also contribute to the NDCV component. We opted, for simplicity, to group all types of disasters, but future LVI users may choose to differentiate among types. A final limitation is that our temperature and precipitation analyses were limited to the available data for 1998–2003. A longer time period may be more appropriate.

4.2. Moma versus Mabote: the LVI–IPCC assessment

Despite the low estimated adaptive capacity of Mabote households resulting from demographic imbalance and high percent of orphan-rearing families, adaptation practices such as livelihood diversification and food and water storage decreased Mabote's overall LVI–IPCC score. It is possible that these strategies will only be able to compensate for climate changes within a narrow band of possible climate variation. Although Moma households did not report similar adaptation strategies, they also did not report the same demographic pressures or low rates of school attendance prevalent in Mabote. Without these competing pressures of raising orphaned children and running a single-parent-headed household (Bollinger et al., 1999; Booysen et al., 2004), families in Moma may have more flexibility to implement different adaptation strategies in the future.

4.3. Limitations of our study and the LVI approach

The sub-components we used to construct the LVI were selected based on a review of available data for our particular study communities and may not apply to other populations. Our intention however was to introduce the LVI concept and demonstrate a particular application. Other sub-components could be used to quantify the major components and other weighting schemes used to reflect local priorities. It is also important to note that we standardized the sub-components using maximum and minimum values for our study population. As noted by Vincent (Vincent, 2007), this means that our LVI estimates are not comparable with future studies unless these are conducted following our methods. Because we designed the LVI for district level assessment, it cannot be merged with climate projections from low resolution GCMs which some may argue would extend the vulnerability analysis further into the future than the LVI allows. Finally, because we did not collect data from households that were empty when the field team visited, we cannot comment on the potential magnitude of the associated selection bias. For example, it is possible that many of the households we did interview were two-adult households where one adult worked outside the home, while the empty households were single adult homes with that adult out working during the interview period. In this case, our data may under represent purportedly more vulnerable single-adult homes.

Limitations of the overall LVI approach include those associated with the use of indicators and indices, namely that these oversimplify a complex reality and there is inherently no straightforward way to validate indices comprised of disparate indicators (Vincent, 2007). Because sub-components are averaged into one major component score, the indexing approach does not incorporate variance between study populations. Further, the selection of sub-components and the assignment of directionality from less to more vulnerable involves normative judgment (Vincent, 2007). Some may debate for example whether a larger fraction of female-headed households increases or decreases a community's vulnerability to climate change impacts.

4.4. Benefits of the LVI and LVI–IPCC approach

The LVI and LVI–IPCC could be used to assess the impact of a program or policy by substituting the value of the indicator that is expected to change and recalculating the overall vulnerability index. For example, if the goal of a water sector intervention is to decrease the travel time to a community's primary water source, the target travel time could be incorporated and a new LVI calculated. The new LVI could then be compared with the baseline LVI to estimate the intervention's effect on the community's climate vulnerability.

Similarly, the LVI might be used to project future vulnerability under simple climate change scenarios (such as a 1 °C increase in temperature). To illustrate, we repeated the LVI calculation, extending the time horizon for 6 additional years by duplicating the temperature and precipitation data and increasing the average maximum monthly temperature by 0.25 °C in Year 7, 0.5 °C in Year 8, 0.75 °C in Year 9, then holding it at 1 °C over the Year 6 temperature for Years 10–12. This scenario had opposite effects on each district, decreasing the NDCV major component and overall LVI for Moma by 0.010 and 0.002, respectively, while increasing the NDCV major component and overall LVI for Mabote by 0.031 and 0.006, respectively.

The LVI and LVI–IPCC utilize household-level primary data to measure the chosen sub-components. Thus this approach does not suffer from the limitations of secondary data-driven methods, namely the consequences of combining data collected at different temporal and/or spatial scales and for different purposes. Further, sources of measurement error in the LVI approach are limited to our household survey methods and to error associated with self-reported data. Researchers relying on secondary data on the other hand often have no information on measurement error thus no way to estimate potential biases in interpretation of results. Further, we were able to demonstrate that it is possible to collect high quality household survey data with low missing response frequencies in resource-scarce communities. In this way, the LVI approach helps avoid the missing data problem affecting many secondary data sources. Finally, the sub-components and weighting structure of the LVI can be adapted to fit the needs of a particular community or end-user where other assessments reviewed here (O'Brien et al., 2004; Thornton et al., 2006; Vincent, 2007; Eakin and Bojorquez-Tapia, 2008) have presented these components as fixed within their assessment frameworks.

4.5. Defining the appropriate scale for livelihood vulnerability assessments

A question that remains is the appropriate scale at which to carry out livelihood vulnerability assessments. CARE's Household Livelihood Security Index utilizes household survey and qualitative data to produce a community assessment of the barriers to household livelihood security (Lindenberg, 2002). CARE utilizes multiple methods to collect data for the index, including community meetings, focus groups, and anthropometric surveys in addition to household interviews (Lindenberg, 2002). Vincent (2007) conducted both national and household level assessments then assigned scores and relative ranks to countries and households, respectively. Eakin and Bojorquez-Tapia (2008), on the other hand, used household surveys to classify households into three vulnerability categories. In the present study, we calculated the LVI at the district level. Future users might attempt this at the community level, however we do not recommend the LVI for household vulnerability assessment for several reasons. Drawing on the food security literature, Eakin and Bojorquez-Tapia (2008) assert that household vulnerability is more dynamic than national-scale vulnerability and should thus be defined on a shorter time scale; for example, that would be required to redistribute resources in an emergency. Assessing vulnerability to climate impacts, on the other hand, might require longer time scales, so that changes in livelihoods, water/food storage practices, and other long-term activities can be incorporated.

Regional influences on climate vulnerability should also be considered when determining the appropriate scale for vulnerability assessment. In their household level analysis, Eakin and Bojorquez-Tapia (2008) point out that the values of many of their indicators were similar across vulnerability categories, and conclude that household livelihood profiles should be viewed within the context of larger regional social and economic processes. Many of our own LVI sub-components, including livelihood strategies, demographic structures, and access to water and health facilities, were similar among households within a particular region. Similarly, natural disasters and temperature/precipitation changes also occur at a regional rather than local scale.

Finally, choice of scale also depends on the objective of the vulnerability assessment. We designed our LVI specifically to inform resource distribution and program design for CARE and other development organizations. To capitalize on economies of scale, these organizations may choose to concentrate resources on interventions at the community/district rather than household level. Examples could include disaster preparedness plans, group agricultural insurance, building health facilities or community water sources, or instituting HIV/AIDS education programs.

5. Conclusion

We presented the LVI and LVI–IPCC as alternative methods for assessing relative vulnerability of communities to climate change impacts. Each approach provides a detailed depiction of factors driving household livelihood vulnerability in a particular region. Formulas for calculating the LVI and LVI–IPCC were designed to be straightforward in order to reach a diverse set of users. Additional information can be gained when two or more study areas are compared using vulnerability spider and triangle diagrams. Limitations of our approach include the subjectivity involved in selecting sub-components and the directionality of the relationship between the sub-components and vulnerability, the masking of extreme values by utilizing means to calculate the indices, and possible selection bias due to empty households left out of the sample.

Replication of this study in the same location over time might provide information about how the exposure, adaptive capacity, and sensitivity of districts change as adaptation practices are initiated. Future work might include refinement of the Social Networks sub-components in order to more accurately evaluate social bonds. Additionally, the LVI approach could be tested at the community level in order to compare vulnerability among communities within a district. Overall, it is hoped that the LVI will provide a useful tool for development planners to evaluate livelihood vulnerability to climate change impacts in the communities in which they work and to develop programs to strengthen the most vulnerable sectors.

Acknowledgements

This research was supported by the Emory University Rollins School of Public Health Global Field Experience Fund, CARE-Mozambique, and the Society for Public Health Education. The authors would like to acknowledge Zaido Abdul, Carmen Ezequiel, Celma Chicico, Claudina, and Delfina for their work in the field as well as the staff of CARE-Mozambique for their logistical expertise.

Appendix A

Calculating the food major component for the LVI for Moma District, Mozambique.

Sub-components for food major component	Sub-component values for Moma	Max sub-component value for study population	Min sub-component value for study population	Index value for Moma	Food major component values for Moma
Percent of households dependent on family farm for food (F_1)	97.5	100	0	0.975	0.364
Average number of months households struggle to find food (range: 0–12) (F_2)	3.76	12	0	0.313	
Crop diversity index (range: >0–1)* (F_3)	0.27	1	0.11	0.180	
Percent of households that do not save crops (F_4)	26.5	100	0	0.265	
Percent of households that do not save seeds (F_5)	8.54	100	0	0.085	

Step 1 (repeat for all sub-component indicators): $index_{\text{Food}_1\,\text{Moma}} = \frac{97.5-0}{100-0} = 0.975$

Step 2 (repeat for all major components): $\text{Food}_{\text{Moma}} = \frac{\sum_{i=1}^{n} index_{s_d i}}{n} = \frac{F_{1\text{Moma}}+F_{2\text{Moma}}+F_{3\text{Moma}}+F_{4\text{Moma}}+F_{5\text{Moma}}}{5} = \frac{0.975+0.313+0.180+0.265+0.085}{5} = 0.364$

Step 3 (repeat for all study areas): $\text{LVI}_{\text{Moma}} = \frac{\sum_{i=1}^{7} w_{M_i} M_{di}}{\sum_{i=1}^{7} w_{M_i}} = \frac{(5)(0.175)+(3)(0.246)+(4)(0.317)+(3)(0.457)+(5)(0.364)+(5)(0.370)+(6)(0.312)}{5+3+4+3+5+5+6} = 0.316$

Appendix B

Calculating LVI–IPCC for Moma District, Mozambique.

Contributing factors	Major components for Moma district	Major component values for Moma	Number of sub-components per major component	Contributing factor values	LVI–IPCC value for Moma
Adaptive capacity	Socio-demographic profile	0.609	5	0.521	
	Livelihood strategies	0.648	3		
	Social networks	0.249	3		−0.074
Sensitivity	Health	0.317	4	0.353	
	Food	0.364	5		
	Water	0.370	5		
Exposure	Natural disasters and climate variability	0.312	6	0.312	

Step 1 (calculate indexed sub-component indicators and major components as shown in Appendix A, taking the inverse of the adaptive capacity sub-component indicators: Socio-demographic Profile, Livelihood Strategies, and Social Networks).

Step 2 (repeat for all contributing factors: exposure, sensitivity, and adaptive capacity): $\text{Adaptive Capacity}_{\text{Moma}} = \frac{\sum_{i=1}^{n} w_{M_i} M_{di}}{\sum_{i=1}^{n} w_{M_i}} = \frac{(5)(0.609)+(3)(0.648)+(3)(0.249)}{5+3+3} = 0.521$

Step 3 (repeat for all study areas): $\text{LVI}-\text{IPCC}_{\text{Moma}} = (e_{\text{Moma}} - a_{\text{Moma}}) * s_{\text{Moma}} = (0.312 - 0.521)(0.353) = -0.074$

References

Arnell, N.W., 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. Global Environmental Change 14, 31–52.

Boddiger, D., 2007. Boosting biofuel crops could threaten food security. Lancet 370, 923–924.

Bollinger, L., Stover, J., Kerkhoven, R., Mutangadura, G., Mukurazita, D., 1999. The economic impact of AIDS in Zimbabwe. The POLICY Project – The Futures Group International, Research Triangle Institute, The Centre for Development and Population Activities Funded by USAID.

Booysen, F., Bachmann, M., Matebsi, Z., Meyer, J., 2004. The socio-economic impact of HIV/AIDS on households in South Africa: pilot study in Welkom and Qwaqwa, Free State Province. University of the Free State, Centre for Heath Systems Research and Development Funded by AusAID, DFID.

Chambers, R., Conway, G., 1992. Sustainable Rural Livelihoods: Practical Concepts for the 21st Century. Institute of Development Studies, UK.

Chen, J.T., Rehkopf, D.H., Waterman, P.D., Subramanian, S.V., Coull, B.A., Cohen, B., Ostrem, M., Krieger, N., 2006. Mapping and measuring social disparities in premature mortality: the impact of census tract poverty within and across Boston neighborhoods, 1999–2001. Journal of Urban Health 83, 1063–1084.

Clark, S.J., Collinson, M.A., Kahn, K., Drullinger, K., Tollman, S.M., 2007. Retuning home to die: circular labour migration and mortality in South Africa. Scandinavian Journal of Public Health 35, 35–44.

DHS (Demographic Health Survey), 2006. Measure DHS: model questionnaire with commentary. Basic Documentation, Number 2.

Eakin, H., Bojorquez-Tapia, L.A., 2008. Insights into the composition of household vulnerability from multicriteria decision analysis. Global Environmental Change 18, 112–127.

Ebi, K., Kovats, R.S., Menne, B., 2006. An approach for assessing human health vulnerability and public health interventions to adapt to climate change. Environmental Health Perspectives 114, 1930–1934.

Ehrhart, C., Twena, M., 2006. Climate change and poverty in Mozambique: realities and response options for CARE. Background report, CARE International Poverty-Climate Change Initiative.

EM-DAT, 2007. The OFDA/CRED International Disaster Database. Université Catholique de Louvain, Brussels, Belgium. www.em-dat.net (accessed 27 December 2007).

Eriksen, S., Brown, K., Kelly, P.M., 2005. The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. The Geographical Journal 141, 287–305.

Fields, S., 2005. Why Africa's climate change burden is greater. Environmental Health Perspectives 113, A534–A537.

Fowler, F.J., 2002. Survey Research Methods, 3rd ed. Sage Publications, Inc., Thousand Oaks, CA.

Fussel, H.M., Klein, R.J.T., 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change 75, 301–329.

Gillis, M., Perkins, D., Roemer, M., Snodgrass, D., 1987. Economies of Development, 2nd ed. Norton, New York.

Government of Mozambique, 2005a. Profile of Mabote District, Inhambane Province. http://www.govnet.gov.mz/ (accessed 27 December 2007).

Government of Mozambique, 2005b. Profile of Moma District, Nampula Province. http://www.govnet.gov.mz/ (accessed 27 December 2007).

Government of Mozambique, 2007. Preliminary results of the 2007 national census. http://www.ine.gov.mz/noticias/rp (accessed 27 December 2007).

Holt, J.B., 2007. The topography of poverty in the United States: a spatial analysis using county-level data from the Community Health Status Indicators project. Prev Chronic Disease 4, A111.

Hosegood, V., Floyd, S., Marston, M., Hill, C., McGrath, N., Isingo, R., Crampin, A., Zaba, B., 2007. The effect of high HIV prevalence on orphanhood and living arrangements of children in Malawi, Tanzania, and South Africa. Population Studies 61, 327–336.

Instituto Nacional de Estatistica, Mocambique (National Institute of Statistics, Mozambique), 2007. Base de dados – Clima (Database – Climate). http://196.22.54.6/pxweb2007/Database/INE/01/13/13.asp (accessed 23 December 2007).

IPCC, 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report. Cambridge University Press, Cambridge, UK.

IPCC, 2007a. Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report (Ch. 9). Cambridge University Press, Cambridge, UK.

IPCC, 2007b. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report (Ch. 11). Cambridge University Press, Cambridge, UK.

Kasperson, J.X., Kasperson, R.E., Dow, K., 2001. Introduction: global environmental risk and society. In: Kasperson, J.X., Kasperson, R.E. (Eds.), Global Environmental Risk. United Nations University Press, New York.

Kasperson, R.E., Kasperson, J.X., 2001. Climate Change, Vulnerability, and Social Justice. Risk and Vulnerability Programme, Stockholm Environment Institute, Stockholm.

Lindenberg, M., 2002. Measuring household livelihood security at the family and community level in the developing world. World Development 30, 301–318.

Mirza, M., 2003. Climate change and extreme weather events: can developing countries adapt? Climate Policy 3, 233–248.

National Institute of Disaster Management (INGC), Department of Geography, University of Eduardo Mondlane, USAID/FEWS-NET MIND, 2003. Atlas for Disaster Preparedness and Response in the Limpopo Basin.

Nhacolo, A.Q., Nhalungo, D.A., Sacoor, C.N., Aponte, J.J., Thompson, R., Alonso, P., 2006. Levels and trends of demographic indicies in southern rural Mozambique: evidence from demographic surveillance in Manhica district. BMC Public Health 6 .

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., West, J., 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. Global Environmental Change 14, 303–313.

Patz, J.A., Campbell-Lendrum, D., Holloway, T., Foley, J.A., 2005. Impact of regional climate change on human health. Nature 438, 310–317.

Patz, J.A., Gibbs, H.K., Foley, J.A., Rogers, J.V., Smith, K.R., 2007. Climate change and global health: quantifying a growing ethical crisis. EcoHealth 4, 397–405.

Polsky, C., Neff, R., Yarnal, B., 2007. Building comparable global change vulnerability assessments: the vulnerability scoping diagram. Global Environmental Change 17, 472–485.

Sullivan, C., 2002. Calculating a water poverty index. World Development 30, 1195–1210.

Sullivan, C., 2006. Global change impacts: assessing human vulnerability at the subnational scale. In: Presented at the International River Symposium, Brisbane.

Sullivan, C., Meigh, J., 2005. Targeting attention on local vulnerability using an integrated index approach: the example of the climate vulnerability index. Water Science and Technology 51, 69–78.

Sullivan, C., Meigh, J.R., Fediw, T.S., 2002. Derivation and testing of the water poverty index phase 1, Final Report. Department for International Development, UK, 2002.

Tadross, M.A., Hewitson, B.C., Usman, M.T., 2005. The interannual variability of the onset of the maize growing season over South Africa and Zimbabwe. Journal of Climate 18, 3356–3372.

Thomas, D., Osbahr, H., Twyman, C., Adger, N., Hewitson, B., 2005. ADAPTIVE: adaptations to climate change amongst natural resource-dependent societies in the developing world: across the Southern African climate gradient. Tyndall Centre for Climate Change Research Technical Report 35.

Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Kristjanson, P., Notenbaert, A., Bekele, N., Omolo, A., 2006. Mapping climate vulnerability and poverty in Africa. Report to the Department of International Development.

UNDP, 2007. Human development reports. http://hdr.undp.org/en/ (accessed 25 December 2007).

UNEP, 2004. Poverty-biodiversity mapping applications. In: Presented at: IUCN World Conservation Congress, Bangkok, Thailand, 17–25 November 2004.

UNICEF, 2008. MICS3 Manual. (Multiple Indicator Cluster Survey).

United Nations General Assembly, 1997. S/19-2. Programme for the Further Implementation of Agenda 21. 19th Special Session, 23–27 June, New York.

USAID, 2007a. Famine early warning systems network (FEWS-NET). http://www.fews.net/ (accessed 24 December 2007).

USAID, 2007b. Mozambique – floods and cyclones. Fact sheet #2, FY 2007. http://www.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/countries/mozambique/fl_index.html (accessed 27 December 2007).

Vincent, K., 2004. Creating an index of social vulnerability to climate change for Africa. Working Paper 56, Tyndall Centre for Climate Change Research and School of Environmental Sciences, University of East Anglia.

Vincent, K., 2007. Uncertainty in adaptive capacity and the importance of scale. Global Environmental Change 17, 12–24.

WHO, 2005. Immunization Coverage Cluster Survey—Reference Manual. WHO Document Production Services, Geneva, Switzerland.

WHO/Roll Back Malaria, 2003. Economic impact of malaria: household survey.

Williamsburg Emergency Management, 2004. Household natural hazards preparedness questionnaire. Peninsula Hazard Mitigation Planning Committee, Williamsburg, VA.

World Bank, 1997. Survey of living conditions: Uttar Pradesh and Bihar. Household Questionnaire, December 1997–March 1998.

World Food Programme, 2007. Vulnerability analysis and mapping (VAM). http://www.wfp.org/operations/vam/ (accessed 24 December 2007).