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Vulnerability modeling for sub-Saharan Africa: An operationalized approach in Malawi

Dylan W. Malcomb [1], Elizabeth A. Weaver*, Amy Richmond Krakowka [2]

Department of Geography and Environmental Engineering, United States Military Academy, 745 Brewerton Rd, Rm 6004, West Point, NY 10996, USA

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A B S T R A C T

This study addresses the need for a policy-relevant climatic vulnerability model in sub-Saharan Africa, where data is typically poor and people are exposed to a wide range of environmental and socioeconomic stressors that are unique to the region. This research applies a multi-scale, multi-indicator methodology that allows policy-makers and experts flexibility to contextualize causal factors in the modeling process through selection of evidence-based variables of vulnerability. This process is easily scaled to stakeholders needs, whether at a state, district or local level. This article provides a framework to assist stakeholders and policy-makers in Malawi to determine what drives vulnerability at a household level, which areas in the country are most vulnerable and where development solutions should be applied. As financial assistance related to climate adaptation increases rapidly in Africa, this article presents timely results for Malawi and an auspicious methodology that can assist other vulnerable countries.

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Introduction

On 12 July 2013, President of Malawi, Dr. Joyce Banda, appointed Halimi Daudi to the position of Minister of Environment and Climate Change Management. During the ceremony, the President challenged Minister Daudi with addressing the problems that emerge from climate change and developing lasting solutions (Mogha, 2013). While Malawi is a forerunner in identifying social and environmental issues related to hydrometeorological events, developing long-term solutions to climate-related problems in Malawi will not be easy task. The challenges Minister Daudi will face include identifying climatically vulnerable populations, determining causal factors of this vulnerability, creating enduring solutions with development partners, and implementing programs that are sensitive to local needs. This monumental task can also be tied to Malawi's fiscal concerns.

Between 2005 and 2008, Malawi received $23,312,579 in financial aid dedicated to climate change assistance and adaptation projects (Weaver & Peratsakis, 2010). This figure only represents 0.83% of the total $2.8bn USD contributed to Malawi during that period (Tierney et al., 2011), but foreign financial assistance for climate adaptation is expected to increase rapidly. The World Bank reported that it lent $4.6bn USD in adaptation finances worldwide, doubling its adaptation lending from 2011 to 2012 (World Bank, 2013). This is part of the expected $30bn USD in fast-start funding pledged in Copenhagen in 2009, while developed countries have also promised to nearly double their current commitments of Official Development Assistance (ODA) by $100Bn USD – all toward climate-related adaptation and development (Weaver & Peratsakis, 2010). For Malawi, ensuring that new streams of development funding are allocated to the households that need it most is a major policy concern.

Malawi is an exceptionally appropriate location to introduce a new methodology to measure climatic vulnerability. Despite being dwarfed by many of its neighboring countries in size, Malawi has one of the densest populations in the region (Fig. 1) and Malawi's population of fifteen million is expected to double by 2035 (World Bank, 2010). Demographic pressure notwithstanding, 85% of the population is rural with most households highly dependent on rain-fed agriculture and limited nearby natural resources, and 80% of these subsistence farmers grow maize as their primary crop (FAO, 2011). Food security is often Malawi's most pronounced issue in this human–environment relationship. In Malawi, the expression "maize is food" is not an understatement. The intensification of maize cultivation has been the leading strategy of the government of Malawi and international development organizations to combat food security – an initiative that grew tremendous

* Corresponding author. Tel.: +1 845 938 4135.
E-mail addresses: Dylan.malcomb@usma.edu (D.W. Malcomb), Elizabeth.weaver@usma.edu, elizabethweaver@gmail.com (E.A. Weaver), Amy.krakowka@usma.edu (A.R. Krakowka).
[1] Tel.: +1 845 938 3509.
[2] Tel.: +1 845 938 3735.

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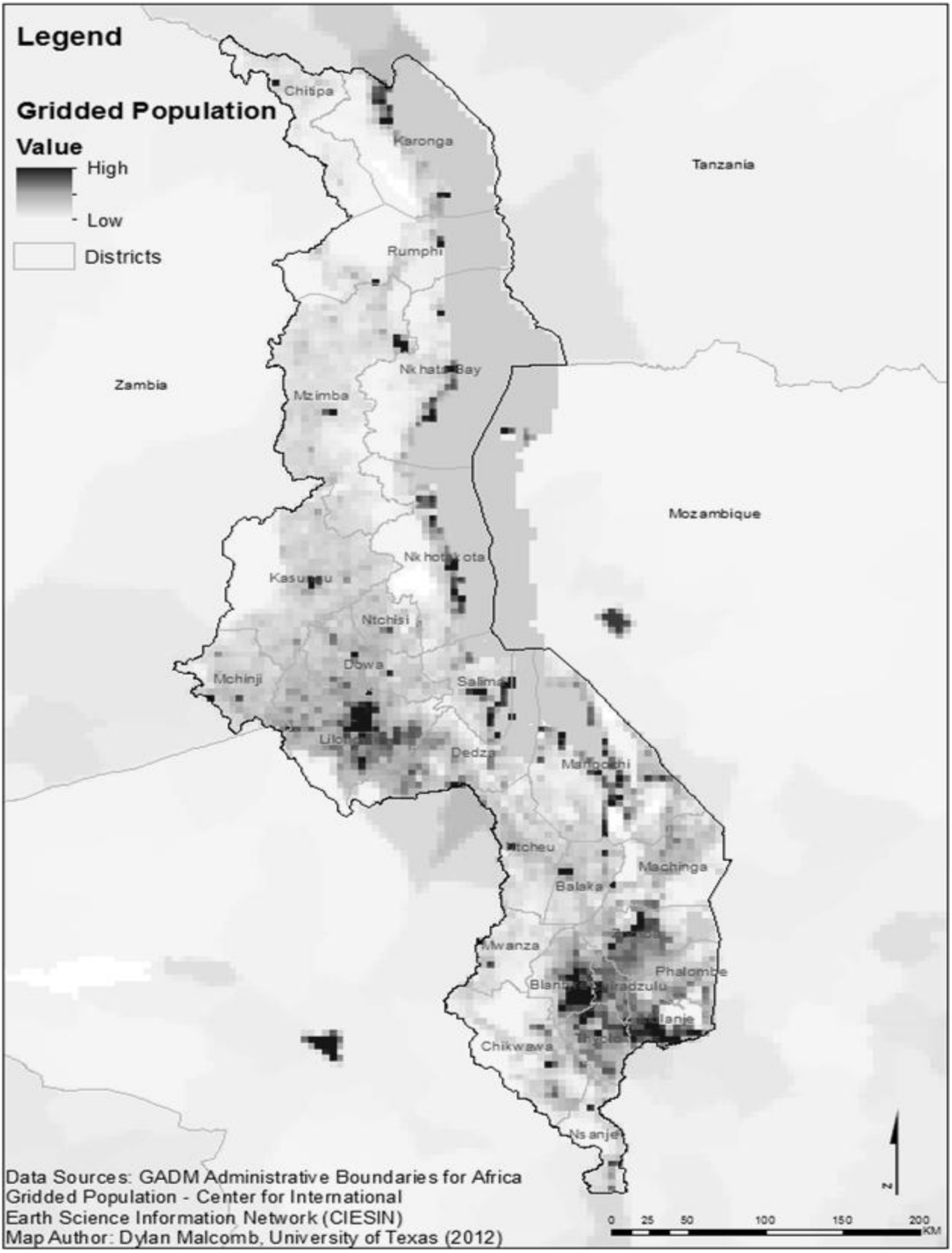


Fig. 1. Map of Malawi, Mozambique, Tanzania and Zambia showing gridded population density.

popularity following a severe drought in 2005. During this event, over 4.2 million people – or 34% of the population – were unable to meet their food needs, and much of the country required some form of humanitarian assistance (FAO, 2005). 2002 had been the sixth year that Malawi experienced a food shortage in the country, and by 2005, it would mark Malawi's worst decade for food security (Cromwell & Kyegombe, 2005). This event highlighted the fact that disasters are often compounding events that expose previous and existing vulnerabilities. This is why issues related to climate change vulnerability must be looked at as part of a more complex system.

It is in this context that a vulnerability analysis of Malawi must consider more than just physical exposure to climate-related hazards. Few existing vulnerability models account for the complex physical and cultural dynamics at the household level and even fewer models use data with sufficient granularity to accomplish this. For this research, we looked temporally across Malawi's most recent decade of natural disasters to develop and apply a new approach to vulnerability modeling; one that can be used by Malawian policy-makers to determine geographic areas most susceptible to hazards, climatic change and variability, and degraded livelihood security. The breadth of this analysis stems from two research trips in Malawi between March and August of 2011. Fieldwork included over seventy interviews with government, non-government and development officials along with focus group interviews in eleven villages. These multi-level, semi-structured interviews with experts and stakeholders were essential in identifying Malawi's distinct socio-ecological issues that included *physical exposure* to recurring floods and droughts, lack of *access* to markets, food, water, health care and labor, reduced *assets* of land, livestock and income and increased *livelihood sensitivity* to market exposure and agricultural practices. To model household-level dynamics, socioeconomic data from Demographic and Health Surveys (DHS) conduct by the U.S. Agency for International Development (USAID) from 2004 and 2010 were incorporated. This resource provides researchers with excellent temporal and spatial coverage. In addition, livelihood data specific to Malawi was acquired through the Famine Early Warning Systems Network (FEWSNET) and physical exposure risk data from the United Nations Environment Programme (UNEP). The paper details the strategy used to develop and apply a new approach to vulnerability analysis to determine areas most susceptible to this combination of social and environmental factors in Malawi.

Complex vulnerability

Vulnerability modeling and mapping is a field of research that has significant policy implications. Indices may be used to prioritize international adaptation assistance (Füssel, 2010), allocate resources (Eriksen & Kelly, 2007), and monitor progress over time (Füssel, 2010; Maplecroft, 2012). However, existing models are rarely sufficient for this purpose. Previous studies have highlighted that many models have disparate objectives (Preston, Yuen, & Westaway, 2011), methodologies (Schröter, Polsky, & Patt, 2005), and scales (Adger & Kelly, 1999), resulting in inflated assessments of climate risk (Busby, Smith, White, & Strange, 2013; Füssel, 2010) or myopic analyses that are useless for comparative analysis (Schröter et al., 2005). In fact, vulnerability assessments are rarely designed to be easily comparable (Polsky, Neff, & Yarnal, 2007). Füssel (2010, p. 8) adds that other weaknesses include "large sensitivity to alternative methods for data aggregation, limited data availability, and hiding of legitimate normative controversies." This is particularly true in Africa where vulnerability assessments must take into consideration a full range of natural hazards, social instability, poor governance, and data that is sporadic or poor quality of data. This is perhaps why Thomas Downing – long an expert in the field – would remark at a conference in 2011 that 'vulnerability mapping is professional malpractice'. This research aims to avoid many of the normative criticisms highlighted in previous assessments (Eriksen & Kelly, 2007; Füssel, 2010; Preston et al., 2011) by using locally derived indicators and granular data in a transparent and easily replicable methodology.

In many regions and on many different scales, researchers have begun mapping, ranking, and comparing vulnerable regions to assist decision makers in the allocation of financial aid (Bohle, Downing, & Watts, 1994; Brooks & Adger, 2003; Brooks, Neil Adger, & Mick Kelly, 2005; Bubsy, Smith, White, & Strange, 2013; Maplecroft, 2012). However, many existing indices of vulnerability have neglected the human dimensions of exposure, resilience and sensitivity by focusing only on indicators of flood, droughts, precipitation and temperature (Adger & Kelly, 1999). Turner et al. (2003) defined vulnerability not only in terms of exposure to hazards, but also the sensitivity and adaptive capacity of the system experiencing the hazard. *Exposure* refers to the magnitude and frequency of forces (e.g. temperature or hydrometeorological disasters) that could stress the system. *Sensitivity* is the degree to which a system will respond to an external disturbing force (Luers, 2005). *Adaptation* – best defined by the IPCC (Parry, Canziani, Palutikof, van der Linden, & Hanson, 2007) – is adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects and that moderates harm or exploits beneficial opportunities (Parry et al., 2007). It is in this context that *Adaptive Capacity* is assessed based on household-level *assets* to recover from disasters and *access* to resources. Collectively, these factors are used in this paper to measure household *resilience*. Resilience – as first introduced in ecology – is a measure of the ability of a system to absorb change-of-state variables, driving variables, and parameters, and still persist (Holling, 1973). Walker, Holling, Carpenter, and Kinzig (2004) would later define resilience as the potential of a system to remain configured and to maintain feedbacks and functions. Resilience has often been closely associated with adaptive capacity (Chapin, Kofinas, & Folke, 2009; Smit & Wandel, 2006), but in this paper it characterizes the ability of a household to prepare for, respond to and recover from complex drivers of vulnerability.

Another issue in vulnerability research has been a recent emphasis on global assessments that select vulnerability metrics across large spatiotemporal regions. These methodologies, designed to rank and compare countries – often using national-level data – have major conceptual issues and result in little consensus on the most vulnerable countries (Kelly & Adger, 2000). Vulnerability research demands critical attention to questions of scale (Adger, Huq, Brown, Conway, & Hulme, 2003; Adger & Kelly, 1999), and Head (2010) has stated that it is important that future adaptation policies include valorization of the local and the individual. At a global scale, there is a dangerous tendency to incorporate easily identifiable variables into a composite index that over-emphasizes issues such as poverty (Kelly & Adger, 2000). Most assessments have bypassed the 'place-based' analysis that is at the heart of vulnerability research (Adger & Kelly, 1999; Schröter et al., 2005; Turner et al., 2003) in favor of generalized global results. This is especially problematic for a small country like Malawi because it is easily overlooked or overshadowed in such errant studies. For example, while Mozambique often tops indices of climatic vulnerability (Brooks et al., 2005; Busby, Smith, White, & Strange, 2012; Busby et al., 2013; Maplecroft, 2012), the southern portion of Malawi experiences a comparable frequency and exposure to hydrometeorological events – the basis for most analysis. What is unseen is that, Malawi had the largest percentage of the population affected by natural disasters worldwide between

1991 and 2000 (EM-DAT, 2012). Moreover, disasters in Mozambique often lead to refugees coming into Malawi, which results in added stress to their southern districts. Large-scale vulnerability indices generally fail to recognize subnational vulnerability dynamics. Interactions of hazards tend to be observed at a 'place' (locally), before they affect 'region' or 'world' (Turner et al., 2003). Therefore, the impacts of climate change on humans should not be measured globally until they are first accounted locally (Adger & Kelly, 1999).

A comprehensive vulnerability analysis accounts for the total system and research must be cognizant that "vulnerability rests in a multifaceted coupled system with connections operating at different spatiotemporal scales and commonly involving stochastic and nonlinear processes" (Turner et al., 2003, p. 8076). When one of the components is stressed, other vulnerabilities, such as poverty, are easily highlighted (Schipper, 2007). Existing problems of natural disasters, climatic variability, land degradation, socioeconomic issues and food insecurity combine to create complex vulnerability in Malawi where intersecting processes drive social instability. Recent studies have linked reliance on agriculture to poverty (Magrath & Sukali, 2009), poverty to natural resource exploitation (Fisher, Chaudhury, & McCusker, 2010; Scherr, 2000) and poverty to the incidence of HIV and AIDS (Gillespie, 2006). These linkages suggest that there are complex processes in Malawi that require a holistic modeling approach.

Fig. 2 shows findings of this complex network as a web of vulnerability pathways that based on the social–ecological environment in Malawi. An extensive literature review drew linkages between seemingly disparate issues that most countries in sub-Saharan Africa face. Hypotheses were formed along each linkage and evaluated during the interview process over two research trips in Malawi. Conversations, especially those at the village level – were critical to confirming these connections between seemingly disparate socio-ecological issues in Malawi. It is worthy to note that this conceptual framework was built on expert-derived and observed linkages of vulnerability prior to the search and application of data. Understanding the complexity of these relationships is imperative to understanding how climate change may not be a vulnerability unto itself, but a vulnerability enhancer that works through an intricate and multifaceted network of suffering.

Evidence-based indicators

Translating this theoretical model into proximate indicators of vulnerability began with a close evaluation of household dynamics. In a review of 45 vulnerability mapping studies, Preston, Yuen, and Westaway (2011) found that only four studies "collected some form of primary data regarding socioeconomic determinants." This research extensively used interviews with experts and villagers in Malawi to identify Malawi's contextual issues. Expert interviews can assist to accomplish four simultaneous objectives as outlined by Tansey (2009). First, they can corroborate what has been established from other sources. Second, they can establish what a set of people think and identify metathemes. Third, they infer about a larger population's characteristics and decisions. Finally, expert interviews can help reconstruct an event or set of events. In the context of this research, all of these objectives were relevant and important.

The focus of the interviews – in addition to perceptions of climate change, adaptation, governance, vulnerability and foreign aid – was on understanding household social and economic practices in the context of environmental uncertainty. Community implementers of several adaptation projects were also interviewed to assess local perceptions of externally designed adaptation projects. Community-level interviews were then interpreted with semi-structured interviews of international development organizations, government ministries and non-governmental organizations. This process tracing of adaptation financial assistance helped to establish a baseline of the government of Malawi's institutional capacity to respond to climate change and the level of coordination present among stakeholders. A list of organizations interviewed is included in Appendix 1.

Once the interviews and fieldwork were complete, transcribed and coded notes revealed that Malawi's drivers of vulnerability (from Fig. 2) were organized along four interview metathemes of 1) *assets* of land, livestock and income, 2) *access* to markets, food, water, health care and labor, 3) *livelihood sensitivity* based market exposure, crop productivity and use of natural resources for coping with disasters and 4) *physical exposure* to recurring floods and droughts. Therefore, this analysis follows a conceptual framework of adaptive capacity (assets and access), sensitivity and exposure that is

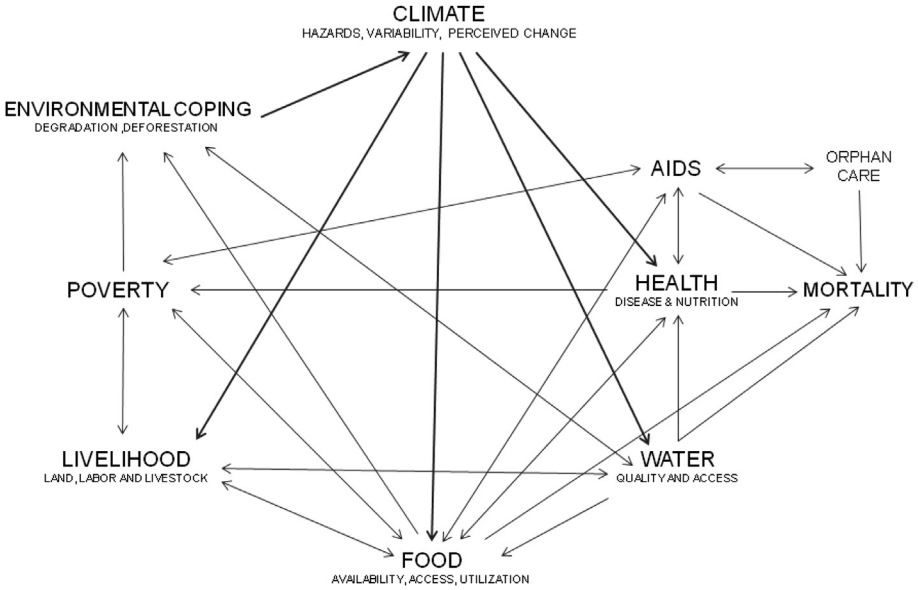


Fig. 2. Vulnerability web (Malawi).

common throughout the literature (Adger & Kelly, 1999; Busby et al., 2012; Schröter et al., 2005; Turner et al., 2003; Wisner & Luce, 1993). The metathemes and selected indicators are detailed below:

Assets are critical to the resilience of households that experience shocks. Research on the impacts of drought in agricultural societies indicates that the use of both income (immediately accessible resources) and wealth (disposable capital assets) are important coping strategies (Adger & Kelly, 1999; Wisner & Luce, 1993). Larger landholders can diversify crops and sell excess food. Animals have historically been used as coping strategy during slow-onset disaster events such as droughts (Conroy, 2006; Malawi Vulnerability Assessment Committee, 2005; Nangoma & Nangoma, 2013). With 12% of the population suffering from HIV/AIDS and as one of the hotspots for infectious disease worldwide (Conroy, 2006), good health is often the difference in a bad or good harvest, poor or moderate income and high or low adaptive capacity. Orphans are a manifest result of the HIV/AIDS epidemic in Malawi and are a highly socially vulnerable subset of the population (Conroy, 2006). Orphan care adds tremendous burden to families that are predisposed poor and food insecure (Magrath & Sukali, 2009). In the context of climate induced disasters and shocks, these indicators represent conditions that increase or decrease household resilience.

Access was one of the most common themes to emerge in interviews with development organizations and rural villages – specifically, access to markets, information and resources. Many interviewees felt that by being well connected to services, basic needs (such as water) and information through radio, mobile technology or tribal networks, households were better prepared, informed and warned about disasters. These concepts parallel many discussions of access that include resources, health care and education (Kelly & Adger, 2000; Watts & Bohle, 1993), markets, insurance and infrastructure (O'Brien et al., 2004), and water and sanitation (Eriksen & Kelly, 2007). Selling of charcoal is one of the top coping strategies during periods of food insecurity and market shocks in many areas of Malawi (Malawi Vulnerability Assessment Committee, 2005). This variable is an issue of access because only 8% of the population has access to the electrical grid (Interview with Malawi Millennium Challenge Corporation, 2011). The burden of collecting water (often at great distances) is a burden that often falls to women and can consume large amounts of time in their daily routine (Magrath & Sukali, 2009). In a time of shock or drought, water collection time can be protracted causing even greater hardship and vulnerability. For some villages, the nearest vehicle-accessible road can be several kilometers and the nearest paved road for public transportation to urban centers might be a days or more journey by foot. Without question, this issue is on the mind of many farmers that seek to sell their excess crops or trade for other food commodities. In the area of early warning and notification, Malawi's expansion of rural radio transmission towers has afforded rural regions with better access to news and information. In interviews with rural farmers conducting adaptation activities, many farmers indicated that they had heard of projects and activities on the radio first and sought to contact the development organizations to participate. Radio programs are powerful tools for reaching previously inaccessible populations and over 50% of surveyed households have radios (Demographic and Health Surveys, 2010). The literature provides several indications that households headed by females are more vulnerable based on less access to sources of power, land and resources (Magrath & Sukali, 2009) and greater burdens based gender inequality, risk of HIV/AIDS (Conroy, 2006; DHS, 2010). In addition, households headed by only one parent or by children (encompassed in the variable of family structure) were seen as more vulnerable in most studies (DHS, 2004, 2010).

Livelihood sensitivity is now a major theme in development. The incorporation of data in this study is based on interviews with the Malawi Vulnerability Assessment Committee (MVAC) and data they created in partnership with the Famine Early Warning System Network (FEWSNET) and USAID. Using pre-established livelihoods zones, these geographic areas are where populations share characteristics of farming practices, labor and environmental coping strategies. They do not generally follow recognized administrative boundaries. Between May and July 2003, the MVAC conducted a livelihood rezoning exercise and a Household Economy Approach (HEA) baseline survey in eleven livelihood zones in Malawi. The director of the MVAC stated that the HEA is based on exchange entitlements and economic theories of risk. Based on the results of this countrywide survey, livelihood zones were created where households share similar options for obtaining food and income. Wealth groups were established by dividing the population into categories of Poor, Middle and Better-Off in a process that was unique to each livelihood zone and based on experts of the assessment committee and district executives. 65% of Malawi's population was considered poor by the MVAC in 2005. Using this data, four indicators were developed to evaluate the sensitivity of Malawi's livelihoods. 1) The percent of food that poor households receive independently from their own farm. This variable is an indication of the sustainability of livelihoods in various zones. 2) The percentage of income that poor households receive from wage labor. Interviews indicate that many households balance their deficits in food production using local wage labor. 3) The percentage of labor income that is susceptible to market shocks (i.e. tobacco, sugar, tea and coffee). 4) Ecological destruction associated with livelihood coping strategies during time of crisis in each zone. These four indicators are unique to this analysis and – with fieldwork that is more robust – could create new and improved methods of vulnerability analysis that more accurately portray social–ecological impacts on livelihoods that extend beyond subsistence farming. The use of these zones as one component of the overall composite vulnerability index helped to smooth the boundaries of TAs used in the assets and access analysis. Similar livelihood data is available in 23 African countries.

Physical Exposure – The historical prevalence of natural disasters in Malawi is a focal point in interviews related to perceived climate change. Floods, droughts and dry spells remain at the forefront of the national psyche. In most interviews, climate change was used interchangeably with variability and conditions relating to disasters. Malawi is routinely threatened by natural hazards that include floods, droughts and dry spells. These events – often in combination – make Malawi one of the most threatened countries in Africa with floods present every year, droughts occurring on average every 3–5 years and persistent dry spells becoming more common in many southern parts of Malawi (EM-DAT, 2012). Between 1979 and 2008, natural disasters in Malawi affected nearly 21.7 million people and killed approximately 2596 (World Bank, 2010). There are now well-established metrics for predicting future risk based on historical occurrences of disaster. For biophysical indicators, existing datasets from the United Nations Environment Programme (UNEP) Global Disaster Risk Platform offer transparent and easily interpretable data on the risks of flood (Peduzzi, 2011) and drought exposure (Peduzzi, 2012). For example, the drought dataset includes an estimate of global drought annual repartition based on two sources: 1) a global monthly gridded precipitation dataset obtained from the Climatic Research Unit (University of East Anglia). 2) a global Standardized Precipitation Index based on Brad Lyon (IRI, Columbia University) methodology. These products are designed by UNEP Global Resource Information Database (GRID)-Europe for the risk evaluation, vulnerability, information & early warning. While use of more localized data may

have better localized the model for Malawi, to expand this model across sub-Saharan Africa in the future, UNEP/GRID offers the greatest coverage.

Table 1 provides a list of these eighteen evidence-based indicators.

Methodology

Following a modeling approach similar to Schröter et al. (2005), this methodology utilized many of their steps for building a comparable vulnerability assessment: define the study area with stakeholders, fieldwork, hypothesize who is vulnerable to what, develop a causal model of vulnerability, find indicators for exposure, sensitivity and adaptive capacity and operationalized the model. At the core of this approach was the contextual fieldwork and interviews with experts and villagers in Malawi. However, pairing observed and realistic perceptions of vulnerability to data that is robust, place-based and relevant is a considerable challenge in any model. The foundation for this vulnerability model was the socioeconomic data provided through DHS (Table 1). Similar data is available in 43 other countries in Africa and these datasets offer a comprehensive set of variables that correspond to many of the reported dynamics in the metathemes of assets and access. These indicators were comprised using over 38,500 household surveys (of which 25,000+ are women) from DHS conducted in Malawi in 2004 and 2010 – the temporal scale used in this analysis.

Table 1
Evidence-based complex vulnerability indicators.

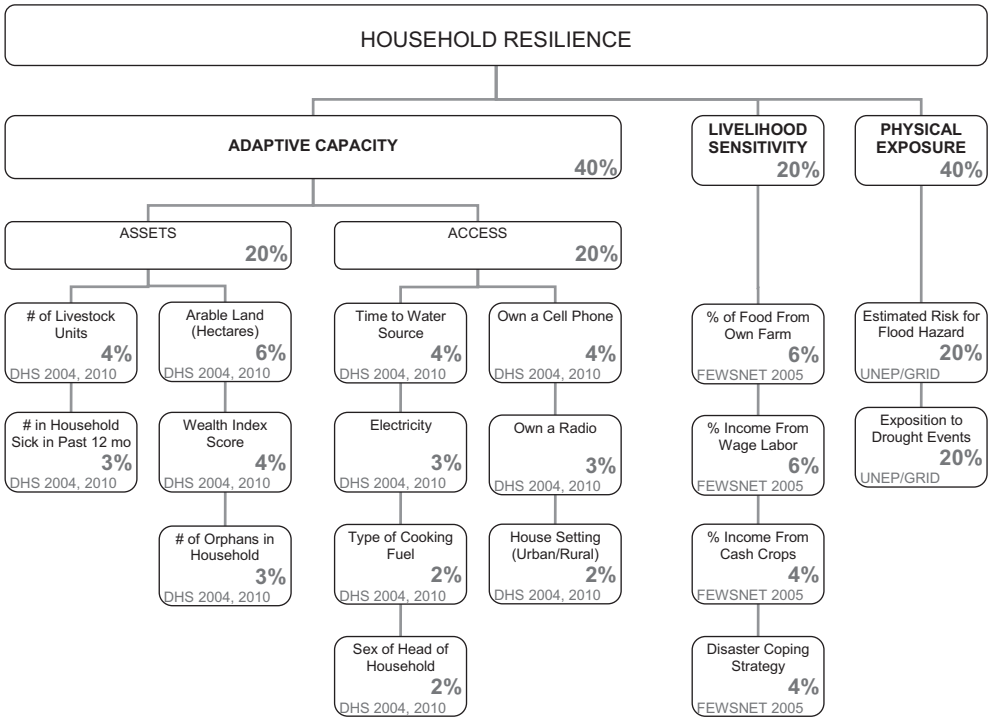
Theory	Indicator	Source of data
Assets		
Arable land	Amount of Arable land per HH	Demographic and Health Survey
Livestock	Number of animals per HH (by type)	Demographic and Health Survey
Money	Wealth index (based on owned assets)	Demographic and Health Survey
Good health	Sick in the past 12 mos	Demographic and Health Survey
Orphan care	Number of orphans or vulnerable children	Demographic and Health Survey
Access		
Basics	Electricity (Y/N)	Demographic and Health Survey
	Cooking fuel type	Demographic and Health Survey
	Water (time to source)	Demographic and Health Survey
Market access	Rural, peri-urban, urban	Demographic and Health Survey
Technology sharing	Own radio (Y/N)	Demographic and Health Survey Media and Information
Media and information	Own a cell phone (Y/N)	Demographic and Health Survey
Power and decision making	Female-headed HH (Y/N)	Demographic and Health Survey
Livelihood sensitivity		
Income source	% Poor income from labor	Famine Early Warning Network
Ability to meet food needs	% Food intake from personal farm	Famine Early Warning Network
Cash crop exposure	% Non-food crop (cotton, tobacco, tea)	Famine Early Warning Network
Ecological coping effect	Access to alternative forms of income	Famine Early Warning Network
Biophysical exposure		
Floods and rain variability	Flood events	UNEP/GRID-Europe
Drought and dry spells	Drought indices	UNEP/GRID-Europe

As a theory-based approach, quantifying and weighting the data is another considerable challenge. Some researchers have used a data-driven approach based on national-level indicators. However, the lack of a well-defined vulnerability outcome to use as a dependent variable is a major issue in a statistical approach (Füssel, 2010). Vulnerability, like happiness, is a human state or condition that cannot be measured directly or in an objective manner (Eriksen & Kelly, 2007). Therefore, finding meaningful variables to form statistical relationships represents a major challenge for a data-driven approach. As a result, expert opinion formed the basis of selecting the most important indicators and weighting them appropriately in this research. "Many composite indices in the field, such as the Freedom House Index or the Ibrahim Index of African Governance, do not have an econometric basis and are externally validated in other ways, such as expert opinion or fieldwork" (Busby et al., 2013, p. 169). However, unlike many theory-based, approaches that only use local opinions to validate a model after the fact, this methodology used experts from the start to build a realistic and localized theory-based model.

Table 2 provides the hierarchy and weighting of the eighteen evidence-based indicators. Each column represents an interview metatheme. Each individual indicator was normalized between zero and five using statistical software, with zero representing the worst condition for a household and five being the best. For example, the poorest quintile of households surveyed was given a wealth index value of zero and the richest quintile, a value of five. Weights were then assigned to each indicator based on the observations, fieldwork, interviews and literature review discussed in the last section. Weighting values were also based on the confidence that indicators were characteristic of the total population. Indicators that were not representative across the country or with the potential for redundancy in the explanatory power of the model were reduced in importance through weighting but not always excluded. This assignment of weighting values is commensurate to the techniques employed in numerous vulnerability studies (Adger & Kelly, 1999; Busby et al., 2013; Polsky et al., 2007; Schröter et al., 2005) where statistical weighting schemes are not practical. However, several iterations of the model using alternate weighting schemes resulted in a final product that best reflects Malawi's contextual and perceptual vulnerability – a stated goal. Selection of alternate indicators from the DHS surveys and expert-based weighting of variables are two measures of flexibility offered to policy-makers when employing this model.

In an indexing approach similar to Oxford University's Multidimensional Poverty index (Alkire, Roche, Santos, & Seth, 2012), DHS indicators were disaggregated to the village level using STATA™ software then combined at a suitable administrative-level for analysis. An explanation on using survey data with GPS information is available from the DHS website and was instrumental in constructing this index. Malawi is divided into 28 administrative districts and this is the common basis for most vulnerability assessments across development sectors that include agriculture, health and education. Districts provide more resources and capacity for planning than villages, but the large geographic areas of some districts make it an inappropriate scale for household vulnerability dynamics. Each district contains segments or hotspots of vulnerable populations that are lost if the data is averaged at this level. Therefore, analysis of the weighted DHS vulnerability indicators was conducted at the administrative scale of Traditional Authorities (TA) in Malawi – one level below districts. While a fine-scale village analysis is possible, TAs offer the lowest level of meaningful administrative

Table 2
Weighted indicators by metatheme.



power. Interviews with governmental, non-governmental and development organizations in Malawi, revealed that many projects and assessments are organized at the TA level. Adaptation projects are commonly coordinated by development organizations through TA chiefs and councils. There are over 250 populated TAs throughout Malawi; this offers a far more detailed analysis than studies at the 28-district level. Using TAs affords district leaders and planners the ability to stratify resources within their own coverage areas.

Because this vulnerability index is contextual to Malawi, the spatial extent includes all territories within Malawi where data was available and excludes all foreign or neighboring areas. While comparative and neighbor analysis is often an objective of vulnerability mapping (Eriksen & Kelly, 2007), this research was limited to observations within Malawi for policy-relevance. Explorations of these border areas and intercontinental dynamics of household vulnerability is an area ripe for future research. The temporal scale for this research is 2004–2010 based on the availability of the Malawi DHS datasets with GPS data. This can be expanded with each upcoming DHS survey, typically conducted every four years.

All work was conducted using ArcGIS™ software to map and visualize the data. Each Metatheme was imported from statistical database files into separate layers in ArcMAP™. Each metatheme layer was then converted to raster format and the overall score was calculated using map algebra and the appropriate weighting. Both adaptive capacity (assets and access) and livelihood sensitivity were modeled as positive conditions of resilience, while exposure risk was modeled as a negative condition. The overall score is represented by the equation: *Household Resilience = Adaptive Capacity + Livelihood Sensitivity − Physical Exposure*.

Results

Mapping vulnerability is a challenging process that involves seemingly disparate data, observations and expertise. Removing subjectivity from this process would be ideal, but is nearly impossible. Even data-driven, inductive approaches cannot fully remove subjectivity (Brooks et al., 2005). This research attempted to minimize subjectivity by using evidence-derived indicators of vulnerability that were drawn from multi-level interviews and observations. Using DHS data, some important and less-bias information was conveyed regarding the wealth and access of households aggregated at the Traditional Authority level. The resultant maps created using this data represent a negotiation of several factors and limitations in order to create the best account of vulnerability at the household level. However, they represent a static view of the historical situation in Malawi (2004 and 2010); they are not projections or predictions of future outcome.

In an attempt to establish a baseline for socioeconomic dynamics in Malawi associated with high and low resilience, Fig. 3 depicts household-level resilience using metatheme categories of assets and access spatially joined to traditional authorities (TA). The data was derived using socioeconomic data from 13,658 household surveys from DHS. On a household basis, the adaptive capacity scores ranged from the lowest of −0.80 to the highest of 39.33. For a household to indicate such a low score (−0.80) is an indication that it was in possession of few assets, had limited access to basic services and required significant time to reach the source of drinking water and/or the presence of vulnerable children. When households were evaluated at the Traditional Authority level, the lowest average score was 3.9 in TA Machinjili in the southern Blantyre District and the highest capacity score was in TA Mposa in the northern district of Machinga (refer to Fig. 1 for district names). The average household score nationwide was 12.74. Because not every traditional authority had surveys conducted within its administrative boundaries, TAs with missing information were indicated as 'Areas Missing DHS Data'. No inferences were made to fill these areas with data. Using the same indicators, Fig. 4 depicts household-level adaptive capacity by TA using 24,850 DHS household surveys conducted across Malawi in 2010. Because of the increase

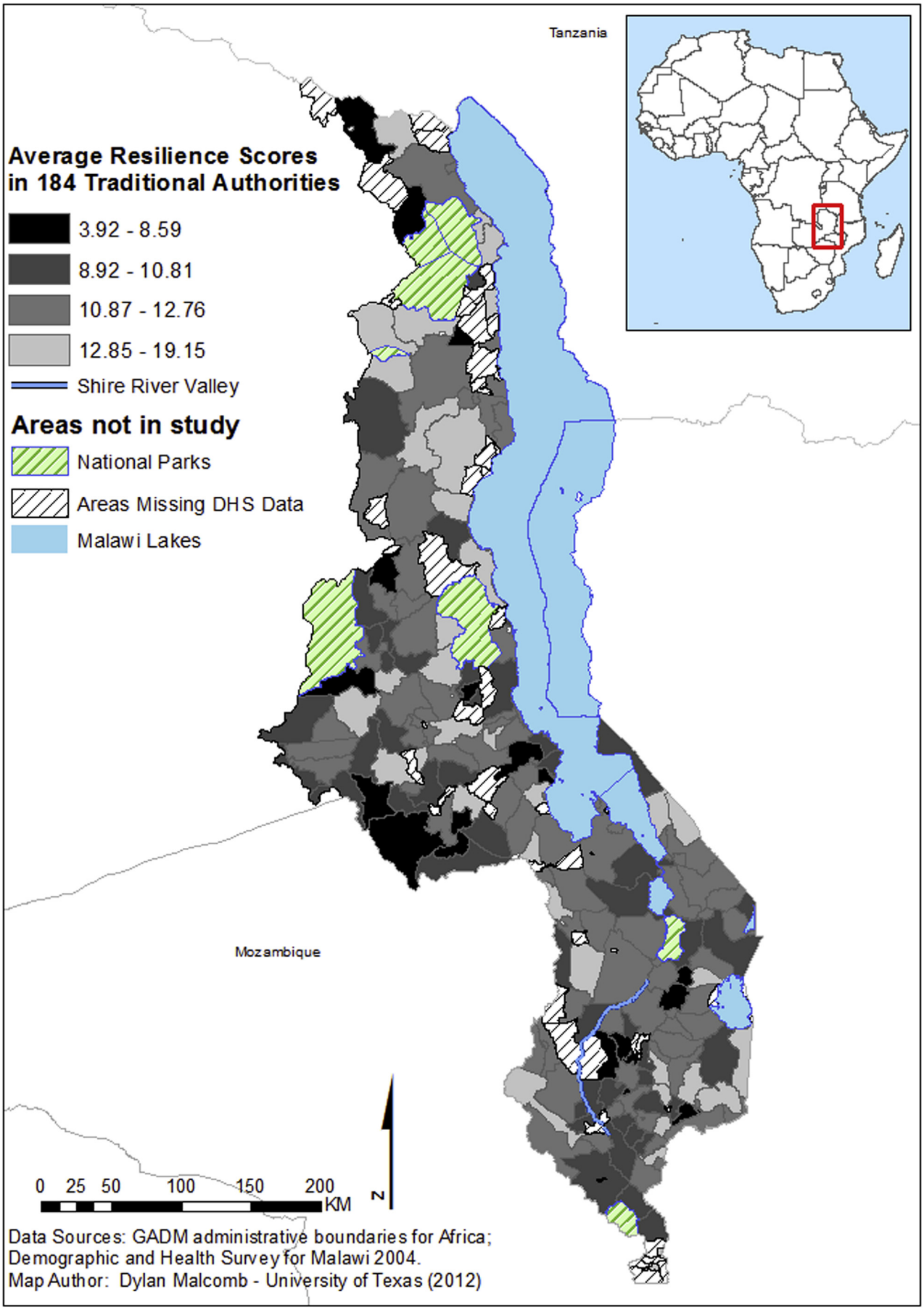


Fig. 3. Malawi Household Resilience (2004) – this map depicts socioeconomic resilience of households in Malawi based on the 2004 DHS indicators along metathemes of assets and access. The scores indicate the average resilience of households by traditional authority. Scores were divided by 'natural breaks' using ArcGIS™.

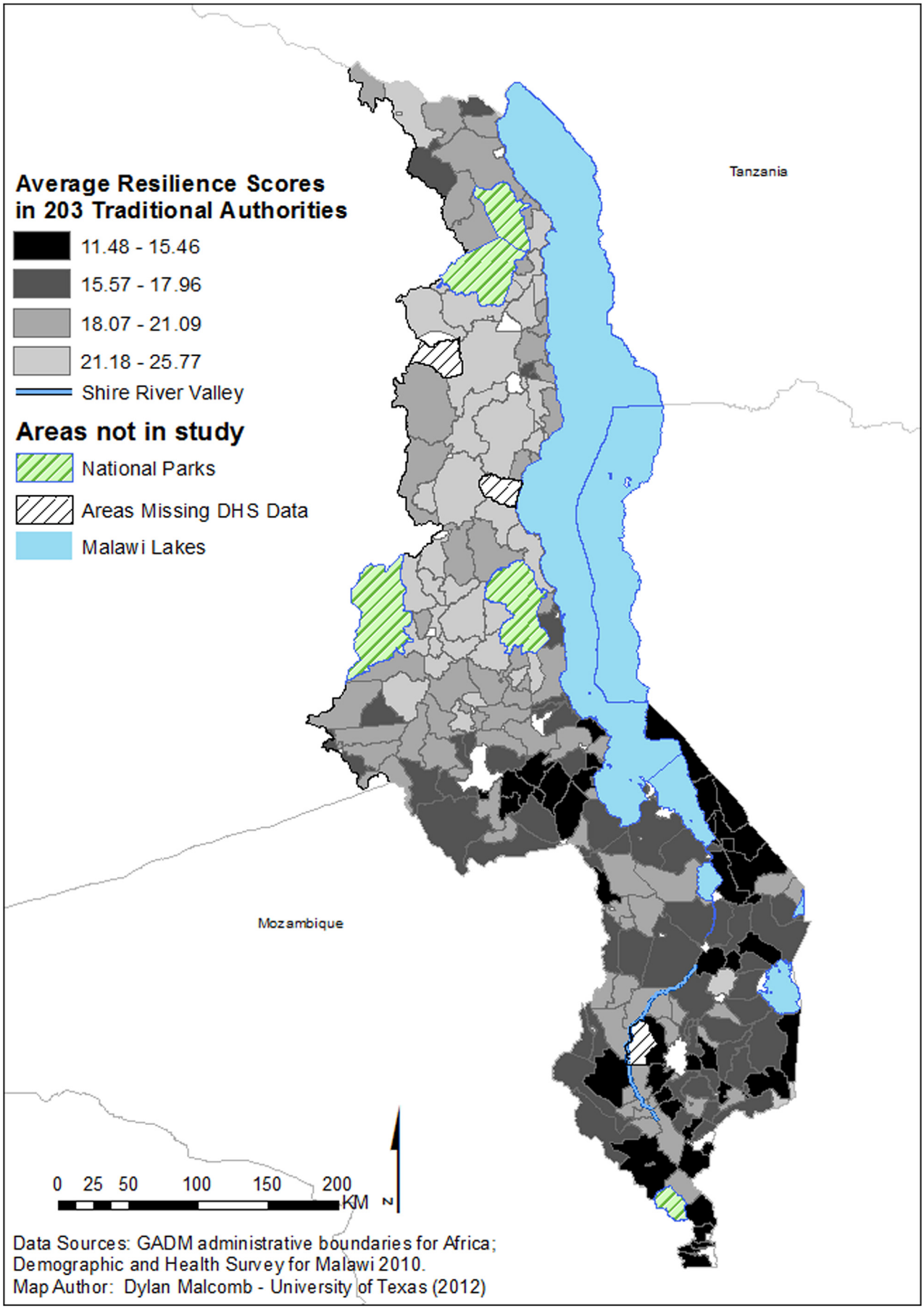


Fig. 4. Malawi Household Resilience (2010) – this map depicts socioeconomic resilience of households in Malawi based on the 2010 DHS indicators along metathemes of assets and access. The scores indicate the average resilience of households by traditional authority. Scores were divided by 'natural breaks' using ArcGIS™.

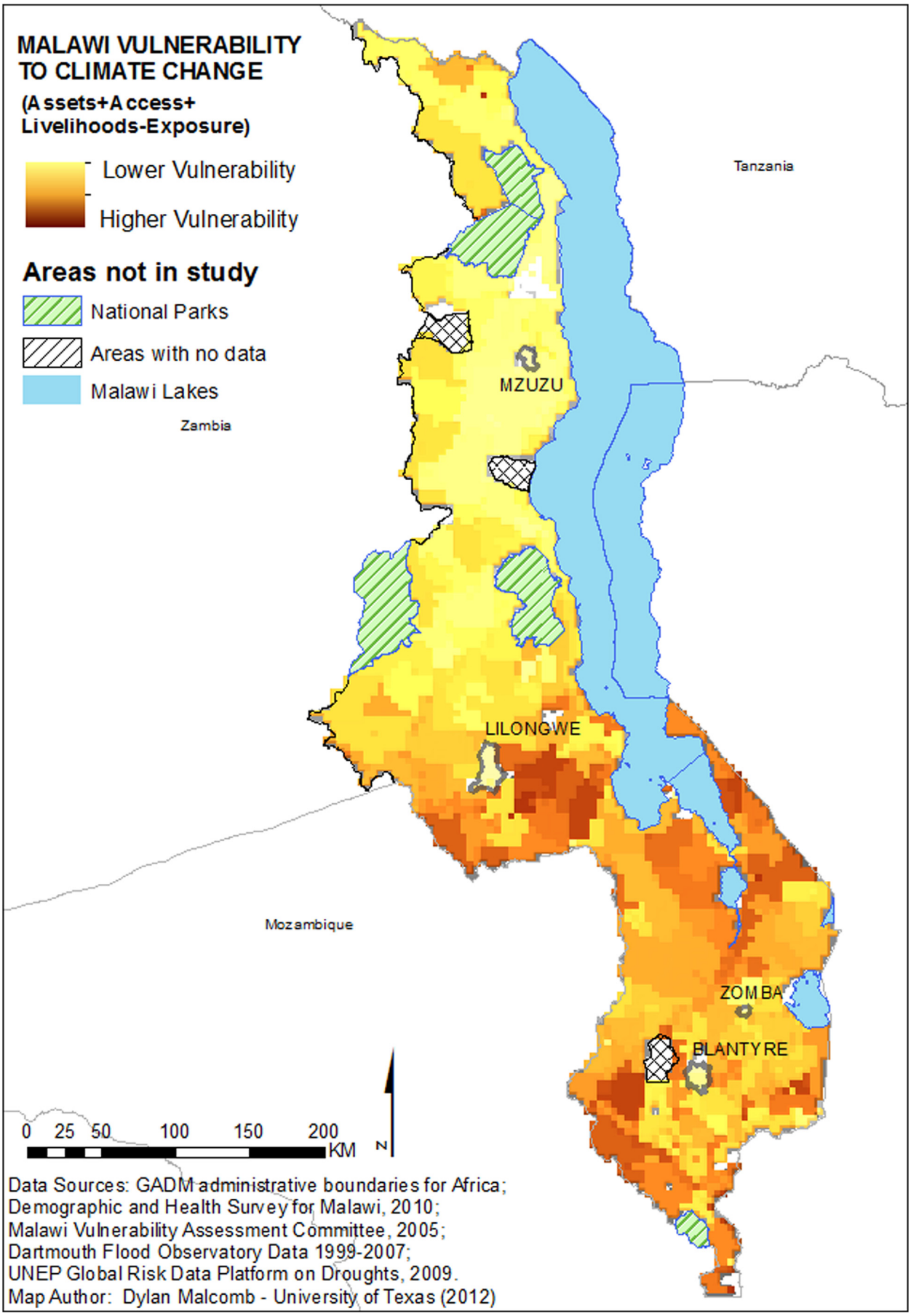


Fig. 5. Malawi Composite Vulnerability Index – this map depicts subnational vulnerability to climate variability and change based on socioeconomic components of assets, access, livelihood sensitivity and exposure to floods and droughts. The darker areas indicate places of a combination of low resilience and high sensitivity and exposure to flood and drought events.

in the overall number of surveys, this map has slightly better TA coverage than 2004.

Whereas in 2004 the spatial distribution of scores illustrated only minor clustering in the southern districts and showed a greater dispersion overall, using the same indicators and weighting, the 2010 map shows significant clustering in Dedza and Machinga on Malawi's southern lakeshore. In addition, there is a noticeable shift in overall vulnerability to the TAs surrounding the major urban center of Blantyre, the districts of Zomba and Mangochi and TAs in the Lower Shire River Valley in the most southern protrusion of Malawi. However, the average score nationwide increased from 12.74 in 2004 to 17.63 in 2010. Concentrations of TAs with higher resilience scores (20+) were exclusively in the northern districts of Rumphi, Nkhata Bay, Kasungu and Nkotakota. Concentrations of the least resilient TAs were in districts of Mangochi, Dedza, Ntchisi and Chikwawa, spread across central and southern Malawi.

Accounting for the shift in vulnerability (lower adaptive capacity scores) to the southern districts of Malawi is difficult using these socioeconomic variables alone. However, major droughts occurred in 2002 and 2005 and experts felt that they affected the south the most. Numerous interviews indicated that many households in this region had not fully recovered from the 2002 and 2005 events. Further analysis of this trend is provided in the discussion section.

While one of the strengths of this methodology is the ability to look at vulnerability across time, these two maps do not take into consideration livelihood sensitivity or physical exposure, for which temporal data was not available. Temporal data was only available in the metathemes of access and assets using DHS. While future efforts to represent exposure and sensitivity data across time are being explored, this was not possible at present.

Fig. 5 combines all indicators of access and assets (2010), livelihood sensitivity and risk of floods and droughts. This index was organized using the normalization between zero and five and the weighting scheme presented in Table 2. Since the livelihood zones are distinct from TAs and the physical exposure data is a continuous raster, the TA's no longer form the basis for aggregating the data. The resultant map provides a truly subnational vantage that illustrates many areas in Malawi that lack the resilience to prepare for, respond to and recover from complex drivers of vulnerability.

Discussion

The intent was for this research to corroborate the perceptions of vulnerability drivers, as well as vulnerable locations, through development of a causal model of household dynamics. In extensive interviews, the Lower Shire River Valley in the districts of Chikwawa and Nsanje was cited – almost unanimously – as the most vulnerable location in Malawi. This area was also cited in the government of Malawi's assessment on climatic vulnerability (GoM, 2005) as the country's most vulnerable location. From constant flooding and droughts to unpredictable rains and the promotion of maize mono-cropping, this southern area of Malawi is often considered the epicenter for future climatic vulnerability and the area in greatest need of adaptation projects and government activities. With an expectation that the districts in the southern portion of the country would be the most vulnerable, the maps created in this research provide evidence that there was a shift in vulnerability to the south following the devastating 2005 famine – a disaster where nearly 40% of the country required food aid. Numerous districts along the upper and lower Shire River exhibited higher vulnerability, and the two southern districts of Chikwawa and Nsanje in particular exhibited near continuous high vulnerability scores. The agricultural officer in this area stated that 45% of the households are food insecure every year as the food produced by the average household only lasts nine months.

The cluster of vulnerable TAs surrounding the major southern city of Blantyre (Fig. 4) was another significant validation of this modeling methodology. Households in these peri-urban areas just outside of Malawi's financial city tend to have fewer assets, virtually no arable land or livestock and very poor access to the city services. These households are often trapped between rural community autonomy and integrated urban centers. This research found that incorporating urban and rural processes into one model is unlikely to be successful and this model does little to explain urban vulnerabilities. However, 85% of Malawians are rural and having a rural-centric index made sense. The ability of this model to capture peri-urban environments is a significant component for policy-makers.

Between 2004 and 2010, there was a clear increase in numerous indicator values that include arable land, livestock and mobile technology. However, as Fig. 4 shows, this increase in adaptive capacity did not occur evenly across the 173 TAs for which there was temporal data (2004 and 2010). Some TAs on average were more vulnerable after the six year study period and some TAs (mostly in the South) grew assets, but at a rate that was slower than the national average. The introduction of mobile technology was highlighted in several interviews as a recent and important phenomenon in Malawi. In 2004, less than 4% of the population had a mobile phone. By 2010, 37% of the population had cell phones (DHS, 2010). The power of this technology to assist households in preparing for and being warned of hazards is an important component in the implementation of future programs related to climate adaptation.

Despite an increase in the country's overall resilience in 2010 over 2004, several traditional authorities were identified that had not surfaced in the literature or interviews. In the southeast corner of Malawi to the east of Blantyre (Fig. 5) are the districts of Thyolo and Mulanje. Interviews with agricultural officers in these districts revealed that the higher vulnerabilities are reflective of the low amount of arable land per household. This is the result of the large tea plantations that have dominated this landscape since colonization. Based on the small plot sizes, few people in this area can own and sustain livestock, which many villagers stated that they could sell during economic or climatic shocks. The clustering of vulnerability along the southern lakeshore area in the districts of Mangochi (just south of Lake Malawi) and Dedza (south of Lilongwe) in Fig. 5 were also not reported in interviews. While there is little doubt that these are poor and vulnerable areas of Malawi, this perceptual omission is perhaps based on the fact that there are fewer observed droughts and floods in this area. In our literature review, the southern lakeshore region was highlighted in an OXFAM report (Magrath & Sukali, 2009) as an area of vulnerability due to overfishing – an issue that was captured in the livelihood sensitivity metatheme of this model. Dedza was highlighted in the government's assessment (2005) based on wildfire risk, but this was not included in our model. These districts are excellent areas of future research because their identification in this map highlights other unknown interacting processes, problems with the methodology or an over-emphasis on indicators such as arable land and livestock.

One of the objectives of this study was to validate and improve upon the vulnerability assessments conducted by the Government of Malawi in the National Adaptation Program of Action (NAPA) (Government of Malawi, 2005). The NAPA, which identifies seven vulnerable districts in Malawi, is a foundational document for the prioritization and future distribution of adaptation funding. The results of this analysis corroborates that there is substantial vulnerability in all of the NAPA-identified districts. However, our maps provide differentiation of vulnerability within the districts and enable more detailed analysis on *who is vulnerable to what*.

Finally, there was an unexpected increase in arable land per household in Malawi from 2004 to 2010 that is worth further analysis. In Malawi, dependence on subsistence agriculture and nearby natural resources is near the highest in the world (Collier, Conway, & Venables, 2008). This research anticipated that household averages of arable land would decrease based on population growth and the subdividing of land, a trend that was explained in several interviews and literature (Booth et al., 2006). However, experts explained that incentives associated with the government's Farmer Input Subsidy Program (FISP) – which provides subsidies of seed and fertilizer to poor households – may actually motivate farmers to expand their arable land for monocropping maize. This extension into marginal lands for farming is an environmentally hazardous practice (Fisher et al., 2010) that may have contributed to the average growth of arable land per household.

Because most vulnerability approaches are theory-driven – or based on a conceptual framework for identifying relevant indicators and determining the strengths of their relationships through weighting (Füssel, 2010) – the significance of the results of this study can be assessed based on the validity of the theoretical approach, the appropriateness of the selected indicators and the reliability of data (Eriksen & Kelly, 2007). Interviews with organizations and individuals at nearly every level of Malawian society were a tremendous component to understanding how Malawians perceive their own vulnerability and threats from external stimuli, including climate change. Climate change was perceived to be present, significant and hazardous in over 90% of the interviews. However, it was observed that many experts and villagers have tremendous difficulty in describing climate change as a threat without including other issues of food security, health and poverty. This qualitative analysis highlights the complexity of vulnerability and the need to fully set climate change within the context of other socio-environmental processes occurring within the given study area.

Conclusion

This research introduced a new multi-scale and multi-indicator approach to climatic vulnerability analysis in Malawi. With experts extensively incorporated in the process to develop localized drivers of complex vulnerability, we utilized innovative socioeconomic, livelihood and exposure risk data to build a localized index model. Multi-level interviews were also critical to understanding local contextual issues and perceptions of climate change, adaptation, governance, vulnerability and foreign aid. This combination of original qualitative and quantitative information allowed us to build an assessment that best reflected the perceived climate hotspots and allowed us to evaluate the specific drivers of vulnerability. This methodology provides policy-makers and experts with the needed flexibility to expand this research spatially (to other to 43 other countries in Africa with DHS data), temporally (based on availability of future surveys) and across vulnerability stimuli (through indicator selection and weighting).

The resultant complex vulnerability maps corroborate the evidence provided through interviews and literature with only minor exceptions or unexpected results that offer future areas for analysis. By focusing on the drivers of vulnerability, these results offer a unique and comprehensive analysis on a subject rarely performed by researchers at this fine scale. It accurately reflects the perceptions of vulnerability to climate change in Malawi while incorporating data from multiple sources to explain why. While the maps serve to validate locations of vulnerable people in Malawi within this short temporal period, the results indicate that the threshold of vulnerability from the best households to the worst is very slight; Malawi is a vulnerable country that experiences a broad range of hazards and stressors.

Interviews with development organizations and government officials revealed that vulnerability assessments would be a key component to determining where future allocations of resources go. Unfortunately, many interviews highlighted that the government's assessments (2005, 2011) lack the necessary depth of analysis needed to allocate future funding properly. For Malawi, identifying drivers of vulnerability, developing enduring solutions and delivering them to the appropriate areas are critical tasks in building trust with the development organizations that steer the development funding and strategy. With the properly scaled and policy-relevant methodology presented in this article, stakeholders and decision makers – like Minister Daudi – can be better prepared to monitor complex vulnerability over time and direct forthcoming aid to the areas that are most in need of assistance.

Appendix 1

What follows is a full list of the interviews conducted in Malawi from March 12–25, 2011 and July 10–August 8, 2011. This list is included as an indicator to the reader of the diversity and expertise of people working on the issues of climate change in Malawi.

Multilateral development organizations

1. European Commission – Head of Rural Development and Food Security
2. United Nations Development Programme – Assistant Resident Representative: Environment, Energy and Climate Change
3. United Nations Development Programme – Programme Analyst for Climate Change, Environment, Energy and Climate Change Cluster,
4. United Nations Environmental Programme – Policy Strategist for Climate Change Adaptation & Development
5. Joint United Nations Programme on HIV/AIDS – Country Coordinator
6. World Bank – Irrigation & Water Specialist

Bilateral development organizations

1. Irish Aid – Head of Development
2. Irish Aid – Second Secretary: Finance
3. United States Agency for International Development – Democracy and Governance Officer
4. United States Agency for International Development Outreach and Communications Specialist
5. Norwegian Agency for Development Cooperation – Second Secretary: Agriculture & Climate Change
6. German Gesellschaft für Internationale Zusammenarbeit (GIZ) – Country Director
7. Japan International Cooperation Agency – Senior Program Officer and Assistant Resident Representative
8. United Kingdom Department for International Development – Climate Change Advisor
9. Millennium Challenge Account – Coordinator and Point of Contact and Environmental and Social Assessment Specialist

Malawi national government

1. Ministry of Finance – Economist and Coordinator for Aid Management Platform
2. The Department of Climate Change and Meteorological Services – Department Chief Meteorologist
3. Malawi Vulnerability Assessment Committee – Technical Advisor, Ministry of Development, Planning and Cooperation

4. Malawi's National Programme for Managing Climate Change – Program Manager – Climate Change, Ministry of Development Planning and Cooperation
5. Environmental Affairs Department, Principal Environmental Officer – Environmental Affairs Department, Ministry of Natural Resources, Energy and Environment

Malawi local government agencies

1. Blantyre City Assembly – Director of the Department of Town Planning and Estate Services
2. Blantyre District Forestry Office – Community Vitalization of the Middle Shire (COVAMS) Project Manager
3. Lower Shire Agricultural Development Division – Chikwawa Crops Officer
4. Lower Shire Agricultural Development Division – Division Agricultural Development Officer for Chikwawa and Nsanje
5. Chikwawa District Forestry Office – District Forestry Officer
6. Chikwawa Environmental Affairs Office – Environmental District Officer – Chikwawa
7. Mulanje Agricultural Development Division – Division Agricultural Development Officer
8. Mulanje Agricultural Development Division – Agricultural Crops Officer

Civil society organizations

1. CARE – Regional Program Coordinator and Programs Director for Food Security/Economic Development
2. International Food Policy Research Institute – Research Fellow: Development Strategy and Governance
3. Innovations for Poverty Action – Country Director
4. Total Land Care – Project Manager of Management for Adaptation to Climate Change (MACC)
5. Total Land Care – GIS Specialist
6. Kickstart UNDP/ATMS Project – Impact Evaluation and Monitoring
7. Coordination Unit for the Rehabilitation of the Environment – Program Officer
8. Civil Society Network on Climate Change – Chair of CISONECC & Director of Churches Action in Relief and Development (CARD)
9. Civil Society Network on Climate Change – Secretariat of CISONEEC & Director of Center for Environmental Policy and Advocacy (CEPA)
10. Danish Church Aid – Humanitarian Response Officer
11. Civil Society Agriculture Network – Coordination Officer
12. Center for Environmental Policy and Advocacy (CEPA) – Communications Officer
13. Action Aid – Program Officer
14. Farmers Union Malawi – Program Officer
15. Evangelical Association of Malawi – Program Officer
16. Norwegian Church Aid – Program Officer
17. Malawi Environmental Endowment Trust – Senior Projects Officer
18. Mulanje Mountain Conservation Trust – Program Officer: Biodiversity Research and Monitoring
19. Sustainable Rural Growth and Development Initiative – Director

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