Vulnerability of agro-pastoral farmers to climate risks in northern and central Tanzania

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ABSTRACT

Agro-pastoral communities have been regulating their livelihood assets in response to global climate change. This paper analyzes the livelihood assets owned by the agro-pastoral communities and how they are used to enhance community resilience so as to reduce vulnerability. Data were collected from 411 agro-pastoralists in five districts of northern and central Tanzania. The analysis was based on indices constructed from carefully selected indicators of exposure, sensitivity and adaptive capacity. Results indicated that the agro-pastoralists in northern Tanzania were more vulnerable to current climate risks than those of central Tanzania. Therefore, the paper recommends that stakeholders create opportunities for non-farm livelihood options to improve the cash income among agro-pastoralists.

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1. Introduction

Climate variability has been and will always be a challenge to human livelihoods. Human-induced climate change has lent a complex new dimension to this challenge. Evidence shows that natural climatic variability, compounded with climate change, will adversely affect millions of livelihoods around the world (IPCC 2007). Climate change is a global phenomenon; however, its impacts vary locally, as do adaptation capacities, preferences, and strategies. Climate change vulnerability can be defined as ‘the capacity to be wounded’ by climate change impacts. In other words, vulnerability implies weak adaptive capacity, whereas strong adaptive capacity means reduced vulnerability (Paavola 2003, 7).

Vulnerability to climate change is considered high in developing countries due to social, economic, and environmental conditions that amplify propensity to negative impacts and contribute to low capacity to cope with and adapt to climate hazards (Cutter, Boruff, and Shirley 2009; Nelson et al. 2010). Extreme events such as droughts and floods have increased vulnerability among farmers who depend on climate conditions. Since these occur regularly, they have been reducing long-term growth and affecting millions of people.

Vulnerability and adaptive capacity can be manifested in and influenced by a number of factors including: (i) human assets, (ii) availability of and access to technological alternatives, (iii) levels and sources of income, (iv) income and other forms of inequality, and (v) aspects of social assets such as trust, transparency, accountability, security of entitlements, and the quality of informal and formal institutions. These features are inadequate in agro-pastoral communities (Eriksen, O’Brien, and Roser-Renntater 2008).

Africa as a whole is considered to be among the most vulnerable regions to climate variability and change due to lack of financial, institutional, and technological capacity. In Tanzania, for example, the gradual increase in temperature and decrease in precipitation that negatively affect agriculture and climate-related risks (mainly drought and floods) impoverish agro-pastoralists in the northern and central parts of the country. Droughts can cause reductions in income and consumption (Pandey, Bhandari, and Hardy 2007). Therefore, understanding vulnerability to such risks of climate extremes among agro-pastoralists is important, as it will inform policy makers on how to devise appropriate strategies and instruments to enhance their resilience. Moreover, effective planning for climate change adaptation programming requires an assessment of local vulnerabilities so as to bridge the gap between community needs and priorities at the local level.
Agro-pastoralists’ livelihood strategies are based on livestock husbandry (Goldman and Riosmena 2013) and crop farming. Livestock and crop sectors in Tanzania are among the worst hit by climate variability via repeated droughts. The issue of vulnerability and impacts of climate change and variability in semi-arid areas of Tanzania has been widely studied (see, e.g. Yanda et al. 2006; Lyimo and Kangalawe 2010; Mongi, Majule, and Lyimo 2010; Goldman and Riosmena 2013; Kangalawe and Lyimo 2013). However, none of these studies have used a vulnerability index calculated from assets owned to measure vulnerability levels among agro-pastoralists. Vulnerability assessment is used to identify the risk posed by climate change and the opportunities for adaptation among agro-pastoral farmers. The present study estimates a vulnerability index using assets owned by agro-pastoral farmers in northern and central Tanzania to determine their vulnerability to climate change.

The paper is structured as follows: Section 2 covers the literature review, which describes the characteristics of agro-pastoral systems in Tanzania and literature on climate change and variability trends in Tanzania. Section 3 describes the methodology used for the analysis and estimation of vulnerability index using data on assets collected from agro-pastoralists. Section 4 presents and discusses the results of the study, while the conclusions and recommendations arising from the results are presented in Section 5.

2. Literature review

2.1. Agro-pastoralism in Tanzania

The pastoral and agro-pastoral system is one of the six broad categories of farming systems (FSs) that are recognized in Tanzania’s agriculture (Food Studies Group 1992). The extent of dependency on livestock farming as a source of livelihood relative to crop farming is used to distinguish between pastoralism and agro-pastoralism. Pure pastoralists entirely rely upon livestock and do not practice crop farming at all, while agro-pastoralists rely on both livestock and crop farming as sources of livelihood. According to Swift (1988), pastoralists are livestock keepers who obtain more than 50% of their gross income from mobile livestock rearing in unimproved communal pastures while agro-pastoralists are livestock keepers obtaining more than 25% but less than 50% of their gross income from livestock on communal grazing land and more than 50% from cropping activities. Rass (2006) defines the two terms more or less the same way as Swift (1988), but emphasizes that pastoralists reside in areas that receive less than 400 mm of rainfall per year with a growing period of 0–75 days where crop farming is not practiced, while agro-pastoralists reside in areas with an annual rainfall between 400 and 600 mm and a growing period of between 75 and 90 days, where millet and sorghum farming is possible.

In Tanzania, agro-pastoralists reside in the Shinyanga, Tabora, and Mara regions in western Tanzania, the Dodoma and Singida regions in central Tanzania and the Kilimanjaro, Arusha, and Manyara regions in northern Tanzania where shifting cultivation of sorghum and millet is practiced. The pastoral areas are typically made up of an undulating plain with rocky hills and escarpments. Altitude ranges from 1000 to 1500 m above sea level. In the plains, the soils are sandy loams, well-drained but with low fertility. Rainfall is highly unreliable and almost all areas are prone to drought; rainfall is uni-modal, varying from 500 to 800 mm. There is a limited resource base and moderate population density (30 per km²) (Food Studies Group 1992). Additionally, diversification of livestock with crop farming and off-farm activities is a common feature in agro-pastoral systems in Tanzania. Livestock-based activities include cattle, goats, and sheep rearing. Crop-based activities include the cultivation of sorghum, finger millet, ground-nuts, bambara nuts, cassava, and grapes, while off-farm activities include the sale of forest products, weaving, knitting, pottery, small businesses, and wage employment (Food Studies Group 1992; Mnenwa and Maliti 2010).

2.2. Climate change and variability trends in Tanzania

The available literature indicates a broad consensus among scientists and the public that climate change has occurred, but disagreement exists on whether it is caused by human activities or by natural factors. On the one hand, proponents of the former argue that increasing human activities, such as the use of fossil fuels, unsustainable agriculture, deforestation, and forest fires have added millions of tons of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, which are responsible for global warming (Antilla 2005; IPCC 2007). The opponents, on the other hand, believe that human activities have nothing to do with global warming, but that it is a result of natural changes that have occurred on the earth over a long period of time (Kaser et al. 2004). Tanzania has experienced several drought and flood disasters. According to Hatibu, Mahoo, and Kajiru (2000), more than 33% of climate shocks in Tanzania over the past 100-year period have been related to drought, which is a major...
pre-cursor of hydrological problems in semi-arid areas. Studies on drought patterns in East Africa (Tanzania, Kenya, and Uganda) and their potential impacts on the economy show that the whole of East Africa was drought-free in 21 out of 100 years (Chang’a, Yanda, and Ngana 2010). Recent experiences of severe and recurring droughts and floods in Tanzania with devastating effects to most vulnerable sectors which include agriculture, forestry, fisheries, energy, health, water, infrastructure, human settlements, and land use include the droughts of 2003, 2005, 2006, 2008, 2009, 2010 and 2011 and the floods of 2009, 2011 (URT 2011; Mbilinyi, Saibul, and Kazi 2013) and that of 2013, which seriously affected most of the vulnerable sectors.

In agro-pastoral areas, prolonged droughts have affected grazing land and decreased water availability for livestock, leading to animal deaths. For example, the drought in the northern part of Tanzania in 2006 caused the deaths of 143,787 animals in the districts of Loliondo, Ngorongoro, Simanjiro, Kiteto, and Mwanga (Mashingo 2010 as cited in Watkiss et al. 2011). Similarly, excessive rains in different parts of the country have affected livestock in pastoral and agro-pastoral systems. The excessive rains that occurred in 2005–2006 affected animals in the rangelands, including the drowning of some animals, destruction of livestock feeds, and outbreaks of Rift Valley Fever (Tumbo et al. 2011).

Climate change projections indicate that the frequency and severity of extreme weather events will continue to escalate to an extent that is more adverse than it is today (Shemsanga, Omambia1, and Gu1 2010). This calls for strengthening climate information and early warning systems to enhance adaption to different types of climate change extremes by agro-pastoral communities. Temperature and rainfall are critical elements of weather and climate in crop and livestock performance in semi-arid areas. An increase in temperature could result in evaporation, which in turn can reduce soil moisture and affect plant growth. To illustrate this, data on temperature trends available from the National Meteorological Stations in Kongwa and Mpwapwa in Dodoma region, Arusha in Arusha region, Mwanga in Kilimanjaro region, and Babati in Manyara region show an increasing trend in temperature over time (Appendix 3, 5 and 6), but at Ikungi meteorological station in Singida region, the temperature was decreasing over time.

Analysis of rainfall trends from the same substations where temperature data were obtained shows a decreasing trend of rainfall in the four districts except Ikungi district where an increasing trend of rainfall was experienced (Appendix 3–7). The decreasing trend of rainfall as a result of climate change had a profound effect on the adaptive capacity of agro-pastoralists in the study areas.

### 2.3. Approaches to vulnerability to climate change

There are many approaches in assessing vulnerability to climate change (Füssel and Klein 2006). Deressa, Hassan, and Ringer (2009) used one of the econometric models to vulnerability known as ‘vulnerability as expected poverty’ (VEP) approach developed by the World Bank (Hoddinott and Quisumbing 2008) to measure the vulnerability of households to climate extremes in the Nile Basin of Ethiopia. Meanwhile, others used Vulnerability as Expected Utility (VEU) (Jha and Dang 2009) and Vulnerability as Uninsured Exposure to Risk (VER) measures all models to assess vulnerability to poverty as used by Hoddinott and Quisumbing (2008). However, the measure VER has the benefit of disaggregating vulnerability due to poverty, and vulnerability due to uninsured risk. Although considered a stronger measure of vulnerability than VEP, VEU is difficult to calculate and relies on panel data which are difficult to acquire (Moret 2014).

Vincent (2004) and Vincent and Cull (2010) came up with weighted aggregate index and equated vulnerability as a function of access to different assets of social vulnerability by choosing some proxy indicators of the determinants of vulnerability focusing on a theoretical framework. Vincent (2004) determines the index at the national level, while Vincent and Cull (2010) apply the same exercise to compute the index at the household level. The two studies concluded that the determinants of vulnerability are scale-specific indicators used for assessing national-scale adaptive capacity and may not be representative at the regional or local level.

Cutter (1996) proposes a synthesis of biophysical and social vulnerability under the hazards of place model, but the model does not consider the climate variables or extremes under its biophysical component. Furthermore, Gbetibouo and Ringler (2009) and Nelson et al. (2010) came up with a more inclusive framework with both biophysical (exposure and sensitivity) and socioeconomic (adaptive capacity) components. The studies adopted a rural livelihoods framework developed by DFID (2000) and Ellis (2000) to measure adaptive capacity. These studies view adaptive capacity as an emergent property of human, social, natural, physical, and financial assets possessed by the community. However, these sustainable livelihood assessments have been criticized because of their failure to consider important contextual
information (Park et al. 2012), as well as providing little opportunity for local stakeholders to shape the assessment (Brown et al. 2010).

The present paper uses the livelihood assets from primary data to construct the adaptive capacity index to avoid pitfalls associated with secondary data (Hahn, Riederer, and Foster 2009). The approach also enables the development of nationally consistent and standardized measures of adaptive capacity (Lockwood et al. 2015). The approach has currently been widely used by several studies (Hahn, Riederer, and Foster 2009; Nelson et al. 2010; Park et al. 2012; Piya, Maharjan, and Joshi 2015). However, the exposure and sensitivity indices were extracted from both secondary and primary data. Several vulnerability studies conducted in Tanzania focus on poverty and climate change in crop FSs (Paavola 2003; Sarris and Karfakis 2006; Lyimo and Kangalawe 2010; Mongi, Majule, and Lyimo 2010), but the present study focused more on the vulnerability of climate-related risks to agro-pastoral FSs in semi-arid parts of Tanzania using Livelihood Vulnerability Index (LVI).

3. Methodology

3.1. Data of the study

The study used both time series and cross-sectional data to analyze vulnerability to climate change among pastoralists in northern and central Tanzania. Time series data on climate trends particularly temperature and rainfall data for the period of 1990–2013 described above were used as indicators of exposure to vulnerability to climate change. Cross-sectional data were collected from selected agro-pastoralists in northern and central Tanzania. In order to ensure good representation of pastoralists in the study areas, one district from each of the five regions of northern and central Tanzania was selected on the basis of agro-pastoralists population. These included Mwanga, Arusha, Babati, Kongwa, and Ikungi district councils in Kilimanjaro, Arusha, Manyara, Dodoma, and Singida regions, respectively. A multistage random sampling procedure was applied to select the regions and districts to be covered by the study. At the first stage, five out of six regions in the two zones were selected as units of sampling. These were selected because of large numbers of agro-pastoralists and being heavily affected by climate change. At the second stage, five districts (elements or group of elements) within the regions (clusters) were sampled as sub-units to derive the final sample. The final sample of 411 was drawn randomly from the study areas using Yamane (1967) formula. This formula assumed 95% confidence level and precision of 0.05; \( n = \frac{N}{1 + Ne^2} \), where \( n \) is the sample size, \( N \) is the population size and \( e \) is the level of precision, whereby farmers (agro-pastoralists) constituted the population for the study. The sample at the district level was drawn proportionately as indicated in Table 1.

Data from sampled agro-pastoralists were collected using a structured questionnaire. The data collected included household characteristics, land, labor, livestock raised, livestock deaths, crops grown, livestock sales, crop sales, on-farm sources of income, social networks, physical assets, and household food security situation. The study also used longitudinal rainfall and temperature observations from 1990 to 2013. The data were entered, processed, and analyzed in Statistical Package for Social Sciences (SPSS) and Microsoft Excel Program to calculate indicators of sensitivity and adaptive capacity as described in the next section.

3.2. Analytical framework and data analysis

Data were analyzed using livelihood vulnerability that was considered in three levels: (i) rise of vulnerable situation due to high level of climatic variability and extreme, (ii) integration of vulnerable situation to agro-pastoral livelihood strategies and assets, and (iii) the need to support vulnerable agro-pastoral communities to make their livelihood sustainable (hence livelihood vulnerability assessment). Thus, the concept of agro-pastoral sustainable development emphasizes linear and consistent development where future agro-pastoral generations will have the equal ability to purchase their livelihood in the same way as the present generation.

3.2.1. Estimation of vulnerability index

The vulnerability of agro-pastoralists to current risks of climate was assessed using LVI. The LVI was assumed as a function of adaptive capacity, sensitivity, and exposure that is \( V = f(I - AC) \), where \( I \) is the impact and AC is the adaptive capacity of the community. These elements of vulnerability were converted into indices using the Human Development Index to calculate the life expectancy index, which is the ratio of the difference

| District | Sample | Percentage |
|---|---|---|
| Kongwa | 110 | 26.8 |
| Arusha | 76 | 18.5 |
| Mwanga | 93 | 22.6 |
| Ikungi | 67 | 16.3 |
| Babati | 65 | 15.8 |
| Total | 411 | 100 |
of the actual life expectancy and a pre-selected minimum, and the range of predetermined maximum and minimum life expectancy (UNDP 2007):

$$\text{Index}_{sd} = \frac{s_d - s_{\text{min}}}{s_{\text{max}} - s_{\text{min}}}$$  \hspace{1cm} (1)

where $s_d$ is the original sub-component for district $d$, $s_{\text{min}}$ is the minimum value, and $s_{\text{max}}$ is the maximum value.

In case of inverse index, for example, livelihood diversification index, the formula is

$$\text{Inverse}_{\text{index}} = \frac{1}{1 + \text{Observed}_{\text{index}}}.$$  \hspace{1cm} (2)

The livelihood index is as function of the inverse of the number of livelihood aspects adopted by a household +1. This means that the lower the livelihood index value the more the livelihood diversity. Therefore, inverting the index gives us a value that tends to be zero which means that people who have diversified their agricultural livelihoods are less vulnerable.

### 3.2.1.1. Exposure indicators.

The study used historical changes in climate variables as indicators for exposure (Table 2). The rate of change in average annual maximum temperature, average annual minimum temperature, and average annual precipitation for the time period of 1990–2013 represents the historical climate changes. The indicators are also used by Coulibaly et al. (2015). The coefficient of the trends of climate variables was calculated separately for each district. It was hypothesized that the higher the rate of change of the climate variables, the higher will be the exposure of the households to climate change and extremes.

Once values for each of the three exposure components for a district were calculated, they were averaged using Equation (3) to obtain the district’s exposure value. The exposure value is expressed as:

$$E_d = \frac{W_{\text{RMT}}RMT + W_{\text{RXT}}RXT + W_{\text{RAR}}RAR}{W_{\text{RMT}} + W_{\text{RXT}} + W_{\text{RAR}}}.$$  \hspace{1cm} (3)

where $E_d$ is the exposure score for a district, RMT is the rate of change in average annual minimum temperature, RXT is the rate of change in average annual maximum temperature, RAR is the rate of change in average annual rainfall, and $W$ is the weight assigned to each indicator.

### 3.2.1.2. Sensitivity index.

Sensitivity was specified by the degree to which a system is modified or affected by an internal or external disturbance or set of disturbances (Gallopín 2006). Livelihood impacts of climate-related disasters in agro-pastoral systems were taken into account as sensitivity indicators. These were livestock deaths and shortage of food at the household level (Table 3). It is hypothesized that higher impacts of past climatic hazards will increase the sensitivity of the households to such events. Apart from these indicators, the income structure also determines the household sensitivity (Piya, Maharjan, and Joshi 2015), whereby the study considered the off-farm income sources as an indicator, with an assumption that a household with a large share of non-farm income sources (composed of salaried jobs, small business, non-farm-skilled jobs, and remittances) will reduce the sensitivity.

The sensitivity score is expressed as:

$$S_d = \frac{W_{\text{LDI}}LDI + W_{\text{FSI}}FSI + W_{\text{SOFI}}SOFI}{W_{\text{LDI}} + W_{\text{FSI}} + W_{\text{SOFI}}}.$$  \hspace{1cm} (4)

where $S_d$ is the sensitivity score for a district, LDI is the livestock death index, FSI is the food security index, SOFI is the share of off-farm to total household income, and $W$ is the weight assigned to each indicator.

### 3.2.1.3. Adaptive capacity.

Adaptive capacity of a household is taken to be an emergent property of the five types of livelihood assets namely human, natural, social, financial, and physical assets (Piya, Maharjan, and Joshi 2015; Dechassa et al. 2016). These indicators are not necessarily specific to climate shocks only, but are related in addressing other shocks like food shortages. Human asset visualizes entitlement to items

### Table 2. Indicator for exposure.

| Component indicator | Description of the indicator | Unit | Hypothesized relation |
|---------------------|------------------------------|------|-----------------------|
| Historical change in climate variables | Rate of change in average annual minimum temperature (1990–2013) | Coefficient of trend | + |
|                      | Rate of change in average annual maximum temperature (1990–2013) | Coefficient of trend | + |
|                      | Rate of change in average annual precipitation (1990–2013) | Coefficient of trend | + |

### Table 3. Indicators of sensitivity.

| Component indicators | Description of the indicators | Unit | Hypothesized relation |
|----------------------|-------------------------------|------|-----------------------|
| Damage to properties | Livestock death index         |      | +                     |
| Food security        | Food security index           | %    | –                     |
| Income structure     | Share of off-farm to total income | %    | –                     |
such as knowledge, level of dependency, labor force, and information access. Such indicators are not directly related to climate shocks, but they are still relevant since the development of human competence through formal education enables households to increase their income by undertaking skilled non-farm activities, which are less climate-sensitive compared to farming and gathering. Moreover, education level provides basic information on individuals’ ability to understand technical aspects of climate information that can improve their decision-making and also to embrace a diverse range of technological and economic opportunities to enhance their livelihoods (Coulibaly et al. 2015). As a result, they assist the households to avert climate risks. Households with higher dependency ratio will have more burdens on the earning members, thereby reducing the adaptive capacity. Another indicator in this asset is access to information devices which increases adaptive capacity through proactive adaptation measures against climate risks.

Natural asset refers to the stock of assets embodied in natural endowments such as land quality, and access to natural resources such as water. In this study, land owned by households is considered as a basic indicator of a natural asset. In addition, the time taken to fetch water and gain possession of a bullock (as a means of plowing fields in the hills) are included as indicators of a natural asset. Northern and central semi-arid areas of Tanzania possess two categories of land, namely wetland, which is more productive than the second category of dry land. A natural asset, by its nature, is more vulnerable to climate shocks than other types of assets. Hence, it is assumed that the higher the share of wetland, the more the harvest for food and other crops, thus higher adaptive capacity; while a large share of dry land implies the opposite (Table 4).

In the context of the sustainable livelihoods framework, a social asset is taken to mean the social resources upon which people draw in pursuit of their livelihood objectives. Such resources are trust and informal safety nets amongst the poor. Trust in rural communities goes hand in hand with membership of Community Based Organizations (CBOs) or Village Saving and Loan Association (VSLA). These organizations improve the households’ social networks and access to information through their constant contact with outsiders during meetings, hence help in pooling risks across the households in a community. In other words, the better the access to credit, the higher the adaptive capacity of the household.

On the one hand, financial assets denote the financial resources that people use to achieve their livelihood objectives. It covers income and poverty issues entailing the household income from major livelihood enterprises such as livestock, crops, and non-farming incomes (Piya, Maharjan, and Joshi 2011). Therefore, the study included gross household annual income, livestock diversification index (cattle, goats, sheep, and pigs), and crop diversity index (maize, sorghum, sunflower, and legumes) as the indicators of financial assets (Table 4). These indicators of financial assets are not specific to climate shocks only. Gross annual income of the household is the sum total of the cash and non-cash income from different sources. Higher income means greater availability of resources to maximize positive livelihood outcomes.

On the other hand, physical assets comprise the basic infrastructure and producer goods needed to support livelihoods. In this study, the main physical assets are type of house, walking distance to the nearest road, and irrigated land (Piya, Maharjan, and Joshi 2015). Out of these, only house quality and irrigation are directly related to climate risks. Possession of better quality house would improve the capacity to withstand the risks from extreme climate events. The type of house was given values of 1 to 3 (refer Table 4), whereby 3 indicated the most durable type of house. The walking distance to the nearest motor road, which in this case was also equivalent to the nearest marketplace, was assumed to be inversely related to adaptive capacity as households located far away from the market would be in a disadvantageous position for lacking the opportunity of income generation from alternative sources like non-farm labor, which help in securing livelihoods during the periods of food shortage or crop failure.

Table 4. Indicators for adaptive capacity.

| Type of asset | Description of the indicators | Unit | Hypothesized relation |
|---------------|--------------------------------|------|-----------------------|
| **Human asset** | Highest qualification in schooling | Schooling yrs | + |
| | Dependency ratio | – | – |
| | Have access to information access (TV, radio, mobile) | Ordinal value | + |
| | (1 = Yes, 0 = No) | | |
| **Natural asset** | Share of more productive land (wet land) in acres | % | + |
| | Share of less productive land (dry land) in acres | % | – |
| | Bullock index | – | + |
| **Social asset** | Trust (1 = Yes, 0 = No) | Ordinal value | + |
| | Received help by the hh | Number | + |
| | Provided help by the hh | Number | + |
| **Financial asset** | Livestock diversification index | – | + |
| | Crop diversity index | – | + |
| | Gross annual income index | Tshs | + |
| **Physical asset** | Type of house (1 = thatched roof, thatched/wooden wall; 2 = thatched roof, stone, and mud wall; 3 = tin/tile roof, stone/wood/brick, and mud wall) | Ordinal value | + |
| | Walking distance to nearest motor road | Minutes | – |
| | Productive resources index | – | + |
Farther distance from the roads also symbolizes poor access to inputs as the service centers are located along the roadsides.

In addition, greater distance from the motor roads also means limited access to information as the marketplace acts as an informal gathering center where information exchange takes place, and where the formal institutions providing extension services are located. Irrigation is directly related to climate shocks, as it minimizes risks posed by droughts. A higher percentage of irrigated land means lesser dependence on natural rain for agricultural purposes, which is becoming more unpredictable with climate change. Therefore, the adaptive index is expressed as:

\[ \text{AC}_d = \frac{W_{HA}HA + W_{NA}NA + W_{SA}SA + W_{FA}FA + W_{PA}PA}{W_{HA} + W_{NA} + W_{SA} + W_{FA} + W_{PA}}, \]

where \( \text{AC}_d \) is the adaptive capacity score for a district, HA is the score of the human assets’ indicators, NA is the score of the natural assets’ indicators, SA is the score of the social assets’ indicators, FA is the score of the financial assets’ indicators, PA is the score of the physical assets’ indicators, and \( W \) is the weight assigned to each indicator.

### 3.2.1.4. Livelihood Vulnerability Index

LVI-based livelihood vulnerability to climate change in the study areas was accessed by an integrated vulnerability assessment approach. The integrated vulnerability approach is superior over other approaches and is particularly useful for policy decision-making (Deressa, Hassan, and Ringler 2010). Integrated vulnerability approach comprises socioeconomic and biophysical indicators of vulnerability and classified these indicators into adaptive capacity, sensitivity, and exposure. The data on adaptive capacity and sensitivity were obtained from primary and secondary sources of data while dichotomous variables, namely river flooding, landslide, and drought on climate extremes captured exposure. Principal Component Analysis (PCA) was performed to compute the component score to weigh the variables to calculate the vulnerability indices. The purpose of using weights obtained from the PCA is to avoid the uncertainty of unequal weighting, given the diversity of indicators used. Vulnerability was calculated as defined by IPCC (2001). Once exposure, sensitivity, and adaptive capacity were calculated, the three contributing factors were combined using the following equation:

\[ V_k = \sum_{i=1}^{n} W_{ki}X_{ki} - \left( \sum_{i=1}^{n} W_{ki}Y_{ki} + \sum_{i=1}^{n} W_{ki}Z_{ki} \right), \]

where \( i = 1, 2, 3, \ldots n \) households; \( k = 1, 2, 3, 4 \) and 5, representing district; \( V_k \) = vulnerability index for \( k \)th district; \( W_{ki} = \) weight obtained from first principal component scores of \( i \)th variable for \( k \)th district; \( Y_{ki} = \) sensitivity \( i \)th for \( k \)th district; and \( Z_{ki} = \) exposure \( i \)th for \( k \)th district.

Thus, agro-pastoral farmers’ vulnerability was scaled from −1 (least vulnerable) to 1 (most vulnerable).

### 4. Results and discussions

#### 4.1. Vulnerability to climate change

A household that is more likely exposed to such a trend of climate change has low levels of human assets, knowledge and access to information (DFID 2000). Again, it suffers from physical and psychological disabilities. Besides, it has few productive and financial assets, suffers from social exclusion or inadequate networks of social support. Likewise, it has limited access to credit and risk-management instruments. Moreover, the vulnerability of the agro-pastoralists is basically influenced by the exposure, which in this study has three indicators as identified in the methodology, sensitivity (three indicators), and adaptive capacity which is made of five livelihood assets (human, natural, social, financial, and physical assets).

#### 4.2. Exposure index

The weights for the indicators of exposure are all positive as hypothesized except for rainfall trend. This implies that while maximum and minimum temperature trends contribute positively to exposure index, the rainfall trend from 1990 to 2013 (for the Arusha, Kongwa, and Mwanga and from 2000 to 2013 for Ikungi district) contributed the opposite (Table 5). However, as indicated by the absolute value of the weights, minimum temperature trend contributes more to exposure index compared to maximum temperature trend. Both minimum and maximum temperature coefficients showed a slow

| Indicators            | Weight | Mwanga | Arusha     | Kongwa      | Ikungi      | p value |
|-----------------------|--------|--------|------------|-------------|-------------|---------|
| Maximum temperature   | 0.961  | 0.023  | (0.734)    | −1.4 (0.514) | 0.027 (0.427) | 0.048 (1.644) | 0.215    |
| Minimum temperature   | 0.980  | 0.000  | (0.37)     | 0.000 (0.467) | 0.57 (0.395) | 0.025 (0.654) | 0.920    |
| Rainfall              | −0.547 | −18 (341.43) | 27.54 (0.533) | 0.00 (196.476) | −0.682 (0.047) | 0.431    |

Note: Figures in parenthesis are standard deviations.
increasing trend for all the study areas except in Arusha, which showed a decrease in maximum temperature trend. The rate of rainfall for Arusha was significantly higher compared to the other districts over the last 24 years.

4.3. Sensitivity index

The three components of sensitivity were extracted from five variables that were assumed as sensitivity indicators. These were total livestock death, average food insufficient months, percentage share of income from crops, percentage share of income from livestock, and percentage share of off-farm income. The results of PCA revealed that components livestock death, insufficient food, and off-farm income explained 81.7% of the variance and therefore were selected as sensitivity components to form the index. The components had the direction of influence as hypothesized with the exception of share of off-farm income which has an opposite direction with that hypothesized (Table 6). It was hypothesized that the share of off-farm income reduces the sensitivity to climate risks among agro-pastoralists. But PCA loaded positive, indicating that the higher the share of off-farm income, the higher the sensitivity. This suggests that such off-farm income sources are highly related to natural resources which are more dependent on climate change and extremes.

However, all of the three indicators chosen for sensitivity index loaded positive weights for sensitivity indicators. Share of off-farm income seemed to influence more to the overall sensitivity index compared to the other indicators of sensitivity. This means that the agro-pastoral farmers have noticed that the climate has changed and they have identified useful adaptation options (off-farm) and implemented them. Among the sampled districts, Arusha district showed higher sensitivity in livestock death index (0.506) but with higher median value of a share of off-farm income indicator (0.431) than other districts. Moreover, farmers in Babati district had the lowest median value of a share of off-farm income to total income of the sampled population (Table 6).

4.4. Adaptive capacity index

The adaptive capacity index represents the average of the individual sub-component (determinant) values, while the determinant values are the average of the normalized indicator values (Cinner et al. 2013). The determinants were obtained from the loading (weights) extracted from PCA five livelihood assets. Results show that the total weights of each of the assets were highly correlated with the adaptive capacity whereby all of the assets were positively correlated to adaptive capacity at p-value 0.05 (Appendix 1). For the human asset, only the highest qualification had the hypothesized relationship, meanwhile the rest (dependency ratio and access to information) had signs which were opposite to the hypothesized relationships. This implies that access to information on climate change reduces adaptive capacity. This might be due to the fact that the majority of farmers ignore such information hence no proactive adaptation is taken by them. Dependency ratio was low and positively related to adaptive capacity among the agro-pastoralists (Table 7). The low dependency ratio implies that the sample households had few dependents, which improved adaptive capacity among the agro-pastoralists. Such results support the finding by Mutabazi (2007) that a household that has a low dependency ratio or does not have dependents at all, is less vulnerable (high adaptive capacity) than a household with a high dependency ratio in terms of entitlements.

For natural assets, owned wet land has a higher impact in determining adaptive capacity, while a higher share of dry land decreases adaptive capacity as hypothesized. However, the agro-pastoralists in the study area have not tapped the potential of dry land, which may contribute significantly to their food security. In these areas, livestock wealth is kept by the agro-pastoralists while the demand for meat, milk and other livestock products is growing rapidly in the internal and external markets.

Furthermore, there is a growing demand for drought-resistant crops such as lablab, sunflower, pigeon peas, green gram, and bambara nuts (ODI 2009). This justifies that the agro-pastoralists have not transformed the dry land challenge into an opportunity to increase their resilience to climate risks. In Turkana (Kenya), some communities have developed traditional water harvesting systems in response to the increasingly frequent droughts, and as a result are able to grow food crops like maize for household consumption and even for sale in local markets (Nyangito, Musimba, and Nyariki 2008). Therefore, agro-pastoralists can change dry land

### Table 6. Weights and median values for sensitivity indicators.

| Indicators                        | Weight | Mwanga | Babati | Arusha | Kongwa | Ikungi | p value |
|----------------------------------|--------|--------|--------|--------|--------|--------|---------|
| Share of off-farm to total income | 0.855  | 0.179 (0.386) | 0.124 (0.267) | 0.431 (0.409)* | 0.175 (0.259) | 0.299 (0.246) | 0.014    |
| Average food security index      | 0.662  | 0.078 (0.082) | 0.078 (0.059) | 0.078 (0.071) | 0.078 (0.058) | 0.078 (0.042) | 0.000    |
| Livestock death index            | 0.060  | 0.034 (0.088) | 0.003 (0.012)* | 0.506 (0.024) | 0.015 (0.021) | 0.002 (0.031) | 0.293    |

Note: Figures in parenthesis are standard deviations.
Table 7. Median values for indicators of adaptive capacity.

| Component indicator | Weight | Mwanga | Babati | Arusha | Kongwa | Ikungi | p value |
|---------------------|--------|--------|--------|--------|--------|--------|---------|
| HUMAN ASSET (HA)    |         |        |        |        |        |        |         |
| Highest qualification | 0.810  | 0.356 (0.137) | 0.356 (0.122) | 0.356 (0.132) | 0.356 (0.143) | 0.338 (0.094) | 0.000 |
| Dependency ratio index | 0.995  | 0.249 (0.235) | 0.199 (0.182) | 0.189 (0.122) | 0.169 (0.178) | 0.169 (0.180) | 0.000 |
| Information devices index | −0.779 | −0.467 (0.086) | −0.467 (0.070) | −0.467 (0.089) | −0.467 (0.112) | −0.467 (0.052) | 0.000 |
| NATURAL ASSET (NA)  |         |        |        |        |        |        |         |
| Share of wet land area | 0.853  | 0.244 (0.368) | 0.071 (0.214) | 0.244 (0.368) | 0.081 (0.255) | 0.039 (0.093) | 0.022 |
| Share of dry land | −0.852 | −0.641 (0.513) | −0.852 (0.272) | −0.852 (0.513) | −0.771 (0.280) | −0.852 (0.946) | 0.000 |
| Possess bullocks | 0.999  | 0.031 (0.063) | 0.084 (0.140) | 0.031 (0.063) | 0.103 (0.166) | 0.069 (0.138) | 0.009 |
| SOCIAL ASSET (SA)   |         |        |        |        |        |        |         |
| Help received by hh index | 0.870  | 0.135 (0.140) | 0.043 (0.101) | 0.077 (0.134) | 0.254 (0.135) | 0.025 (0.080) | 0.006 |
| Help provided by hh index | 0.885  | 0.017 (0.110) | 0.017 (0.045) | 0.069 (0.122) | 0.241 (0.226) | 0.035 (0.053) | 0.001 |
| Trust | 0.279  | 0.077 (0.134) | 0.043 (0.102) | 0.025 (0.080) | 0.066 (0.119) | 0.135 (0.140) | 0.021 |
| FINANCIAL ASSET (FA) |         |        |        |        |        |        |         |
| Livestock index | 0.634  | 0.254 (0.143) | 0.254 (0.125) | 0.254 (0.121) | 0.052 (0.199) | 0.254 (0.166) | 0.000 |
| Crop index | 0.730  | 0.489 (0.199) | 0.489 (0.204) | 0.489 (0.203) | −0.788 (0.221) | 0.489 (0.232) | 0.000 |
| Gross income index | 0.583  | 0.006 (0.015) | 0.006 (0.078) | 0.006 (0.024) | 0.012 (0.062) | 0.023 (0.022) | 0.010 |
| PHYSICAL ASSET (PA) |         |        |        |        |        |        |         |
| Irrigated land | 0.810  | 0.235 (0.369) | 0.037 (0.171) | 0.032 (0.159) | 0.052 (0.199) | 0.0 (0.000) | 0.193 |
| House type | −0.788 | −0.788 (0.299) | −0.788 (0.279) | −0.788 (0.128) | −0.788 (0.221) | −0.788 (0.164) | 0.020 |
| Walking time to road index | 0.400  | 0.012 (0.059) | 0.004 (0.021) | 0.004 (0.005) | 0.012 (0.062) | 0.004 (0.015) | 0.232 |

Note: Figures in parenthesis are standard deviations.

Table 8. Median values of sub-indices for adaptive capacity.

| Assets | Weight | Mwanga | Babati | Arusha | Kongwa | Ikungi | Overall | p value |
|--------|--------|--------|--------|--------|--------|--------|---------|---------|
| HA     | 0.527  | 0.083  | 0.059  | 0.102  | 0.005  | 0.093  | 0.145   | 0.017   |
| NA     | 0.505  | 0.329  | 0.602  | −0.366 | −0.401 | −0.778 | −0.018  | 0.536   |
| SA     | 0.406  | 0.289  | 0.154  | 0.334  | 0.233  | 0.196  | 0.269   | 0.052   |
| FA     | 0.555  | 0.719  | 0.701  | 0.804  | 0.679  | 0.826  | 0.714   | 0.000   |
| PA     | 0.306  | 0.381  | 0.609  | −0.675 | −0.617 | 0.742  | 0.124   | 0.787   |

into a vibrant and productive livelihood system. Another variable was the possession of a bullock, which has more influence on adaptive capacity among the three chosen indicators for natural assets in influencing the household adaptive capacity in the study areas.

For social assets, all indicators selected (trust among the farmers and received and provided help by the household) have signs as hypothesized. However, provided help by the household has the highest influence on adaptive capacity followed by received help by the household. This shows that agro-pastoralists have good social networks (Table 7).

With regard to financial assets, all three indicators have loaded positively as hypothesized. However, crop diversity index has the highest weight followed by the livestock diversification index. The financial assets have the highest weight of all assets, implying that assets had increased the adaptive capacity of the farmers. Normally, greater financial assets mean greater ability to recover from material loss (Swanson et al. 2007), such as food insecurity and death of livestock.

Under physical assets, the percentage of irrigation among agro-pastoralists had the highest influence followed by distance to a road. Table 7 shows that the walking time to the nearest road has a positive influence on adaptive capacity, which is contrary to the hypothesized relation that the longer the walking time to the nearest road, the lower the adaptive capacity. The positive relationship suggests that the longer the walking time to the nearest road, the more the agro-pastoralists increase their chances (adaptive capacity) of learning through interaction with others and thus increase their adaptive capacity.

Listed in Table 8 is the overall adaptive capacity index of the agro-pastoral farmers in the five districts, the median values for each of the five main components, and the weight values for the indicators that are averaged to obtain each component value. Results show that there is no significant difference among the farmers in the districts for natural and physical assets. The financial asset has the largest overall median value and there was a strong statistical difference among the district at the 1% significance level, showing that the asset contributes greatly to the adaptive capacity of the agro-pastoral farmers in reducing the livelihood vulnerability under climate change.

The development of human assets in terms of education and skills enhances proper utilization of existing other assets and internalization of information related to early warning systems and community preparedness plans, which may help them and the communities in districts prepare for extreme weather events (Hahn, Riederer, and Foster 2009). Seasonal weather forecasts distributed through local farming associations may help farmers time their plantings and prevent the...
diversion of scarce water resources for irrigation. Furthermore, local institutions and social networks are equally crucial as demonstrated by the importance of social assets despite the shortcomings they may have. Physical assets have the least weight but have an overall median greater than that of natural assets (Table 8). Thus, improving adaptive capacity against climate extremities requires a diversification of livelihood activities that is less dependent on natural resources.

### 4.5. Vulnerability index

The exposure, sensitivity, and adaptive capacity indices were separately calculated resulting in the districts’ vulnerability index. This paper assumes a linear combination among the three components of vulnerability (exposure, sensitivity, and adaptive capacity) as applied by Dhakal et al. (2013) and Piya, Maharjan, and Joshi (2015). However, works in depicting the exact relationship existing among these components are recommended as others have done (Hahn, Riederer, and Foster 2009; Marshall et al. 2013; Madhuri, Tewari, and Bhowmick 2014). Findings show that farmers from Ikungi district had the highest median value of exposure (0.35) (Table 9), implying that the farmers in the district are highly exposed to climate change, as the areas experience an increase in temperature and decrease trend of rainfall. Moreover, the farmers in Ikungi district had a high sensitivity median score value and low adaptive capacity. Moreover, the agro-pastoralists in Arusha district scored the highest median value of sensitivity index but a relative high adaptive capacity compared to other areas in the study area. Generally, the farmers in the study area had a low adaptive capacity to climate change (Table 9). This accelerated vulnerability among the agro-pastoral farmers.

Based on the LVI, the overall median value LVI score for the farmers in the districts is 0.271 while the mean is 0.363. This study used the median value as a threshold while agro-pastoral farmers in Babati and Kongwa were less vulnerable.

These results show how the vulnerability of agro-pastoral farmers compared to each other demonstrates which component(s) of vulnerability contributed the most to their vulnerability, so that specific actions could be taken for each of them. For example, Mwanga had a high vulnerability mainly due to its high exposure and high sensitivity (Cinner et al. 2012) and low adaptive capacity. Actions to improve the vulnerability of this community might focus on increasing the adaptive capacity (since it is harder to have actions that can reduce exposure). The agro-pastoralists in Arusha district are more vulnerable primarily because of its high sensitivity score while the agro-pastoralists in Babati district are less vulnerable due to low exposure and sensitivity. However, other resilience indicators, though not included in the analysis, could also improve due to public investments in (protective) infrastructure and increased institutional capacity as countries develop (Balica, Wright, and van der Meulen 2012). Therefore, actions to improve the vulnerability of this community might focus on decreasing sensitivity.

### 5. Conclusions and recommendations

The objective of this paper was to analyze the vulnerability of agro-pastoralist farmers to risks associated with climate change in northern and central Tanzania. The vulnerability index revealed that agro-pastoral farmers in the northern zone were more vulnerable than in central Tanzania, while the agro-pastoral farmers in Arusha, Mwanga, and Ikungi were more vulnerable than those from Kongwa and Babati districts. However, their vulnerability was contributed to by exposure to climate risks, sensitivity (internal and external disturbances), and the households’ adaptive capacity. The Sensitivity and adaptive capacity of households were found to have a direct policy implication since they can be controlled by humans. This is confirmed in the analysis of the livelihood assets, which determine adaptive capacity indicating that farmers in Ikungi district did not fare well in all the five assets (sub-components). However, any intervention on improving adaptive capacity would reduce vulnerability among agro-pastoralist farmers.

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**Table 9. Index score for vulnerability and its main components.**

| Indices         | Mwanga   | Babati   | Arusha   | Kongwa   | Ikungi   | $p$ value |
|-----------------|----------|----------|----------|----------|----------|-----------|
| Exposure        | 0.089 (0.089) | 0.049 (0.049) | 0.059 (0.059) | 0.086 (0.086) | 0.350 (0.350) | 0.004     |
| Sensitivity     | 0.196 (0.272) | 0.040 (0.105) | 0.243 (0.261) | 0.040 (0.097) | 0.205 (0.192) | 0.007     |
| Adaptive capacity | $-0.141 (-0.070)$ | $-0.144 (-0.112)$ | $-0.105 (-0.090)$ | $-0.136 (-0.113)$ | $-0.408 (0.140)$ | 0.000     |
| Vulnerability   | 0.390 (0.431) | 0.234 (0.266) | 0.405 (0.409) | 0.265 (0.296) | 0.399 (0.381) | 0.000     |

Note: Figures in parenthesis are mean.
Furthermore, the households that are more vulnerable in Arusha district showed the highest sensitivity score compared to farmers from other districts. Therefore, creating opportunities for non-farm livelihood options, which will improve the cash income among agro-pastoralists, will reduce their dependency on crops and livestock and the other natural resources that are volatile to climate change.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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Appendices

Appendix 1. Correlation of adaptive capacity components

| Assets       | Human | Natural | Social | Financial | Physical | Adaptive capacity |
|--------------|-------|---------|--------|-----------|----------|------------------|
| Human        | 0.098 |         |        |           |          |                  |
| Natural      |       | −0.021 |        |           |          |                  |
| Financial    | −0.041| 0.257** | −0.081 |           |          |                  |
| Social       |       | −0.047 | 0.095  | −0.086    | 0.005    |                  |
| Physical     | 0.595**| 0.245** | 0.278**| 0.471**   |          |                  |
| Adaptive     | 0.698**| 0.298** |        |           |          |                  |

** is 0.05 significance level.

Appendix 2. Median values of vulnerability indicator scores in northern and central Tanzania

| S/N | Indicators       | Northern      | Central     | p value |
|-----|------------------|---------------|-------------|---------|
| 1   | Exposure score   | 0.059 (0.068) | 0.066 (0.074)|         |
| 2   | Sensitivity score| 0.113 (0.223) | 0.044 (0.131)|         |
| 3   | Adaptive capacity score| −0.143 (−0.099) | −0.143 (−0.122) |         |
| 4   | LVI              | 0.306 (0.390) | 0.271 (0.327) | 0.04    |

Appendix 3

Figure A1. (a) Mean annual minimum temperature – Arusha district (1990–2013). (b) Mean annual maximum temperature – Arusha district (1990–2013). (c) Annual rainfall – Arusha district (1990–2013).

Appendix 4

Figure A2. (a) Mean annual minimum temperature – Ikungi district (2002–2013). (b) Mean annual maximum temperature – Ikungi district (2002–2013). (c) Annual rainfall – Ikungi district (2002–2013).
Appendix 5

Figure A3. (a) Mean annual minimum temperature – Kongwa district (1990–2013). (b) Mean annual maximum temperature – Kongwa district (1990–2013). (c) Annual rainfall – Kongwa district (1990–2013).

Appendix 6

Figure A4. (a) Mean annual minimum temperature – Mwanga district (1990–2013). (a) Mean annual maximum temperature – Mwanga district (1990–2013). (c) Annual rainfall – Mwanga district (1990–2013).

Appendix 7

Figure A5. Annual rainfall – Babati district (1990–2013).