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Projections of maize yield vulnerability to droughts and adaptation options in Uganda

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ABSTRACT

Sub-Saharan Africa is likely going to experience more intense and frequent droughts with high parallel possibilities of ramifications on maize yields. While there is a lot of scholarship dwelling on the ramifications of droughts on maize yields at the level of Africa, little has been researched at lower scales. This study presents past (1960–2014) vulnerability of maize yields to droughts based on a previous study (Epule et al., 2017) and projects the future vulnerability of maize yields to droughts by calculating the sensitivity, exposure and adaptive capacity of maize yields to droughts for the period 2015–2050. The results show that maize yields are more vulnerable in the north of Uganda for the period 1960–2014. However, adaptive capacity is higher in the south. Maize yields also record higher levels of sensitivity and exposure in the north with the latter patterns explained by variations in precipitation, temperature, rich volcanic soils, access to rivers and lakes. In terms of future vulnerability for the period 2015–2050, this study shows that the level of vulnerability of maize yields to droughts in Uganda will increase to levels higher than what currently obtains. For example, the vulnerability index will increase from 0.54 under the 1.5 °C to 0.70 under the 2.0 °C and to 1.54 under the 2.5 °C scenario. Sensitivity is also likely to increase while exposure and adaptive capacity are most likely to remain the same. Overall, it can be said that the future of maize production in Uganda under present and future circumstances remains very bleak without concrete actions. As a way forward, land use policy designers will have to integrate water management, agroforestry, climatic information diffusion, training and indigenous knowledge into land use planning decisions in the context of agriculture.

1. Introduction

In the last 35 years, most African countries south of the Sahara have witnessed a 0.2–2.0 °C increase in temperatures (IPCC, 2007). Because agriculture in most of Africa depends on precipitation, agricultural systems face daunting climate related challenges (Parry et al., 2004; Challinor et al., 2008; Schlenker and Lobell, 2010; Ford et al., 2009; Ford, 2009; Thomson et al., 2010; Ford et al., 2013; IPCC, 2014), as small-scale farmers continue to be at the forefront of agricultural production in sub-Saharan Africa (SSA) (Challinor et al., 2010; Müller et al., 2011). There is currently a need for integrative approaches that monitor the climate of most African countries (Cooper et al., 2008; Shi and Tao, 2014). This is important because the degree of droughts will be reflected in the degree of vulnerability, exposure, sensitivity and adaptive capacity of cropping systems (Simelton et al., 2009; Fraser, 2003, 2006; Comenetz and Caviedes, 2002; Green, 1993).

Agriculture contributes about 20% to the gross domestic product (GDP) of Uganda, 48% to export earnings (Kaizzi, 2014), and employs about 73% of the population. A huge fraction of the population of Uganda depends on small-scale farming for their livelihoods (Kaizzi, 2014). Poverty reduction in Uganda is contingent on improvements in agriculture (Poate, 1988; IFAD, 2012; Kaizzi, 2014). In Uganda, major droughts in the last decades have had significant impacts, including in 2006 that resulted in higher food prices, and droughts in 2008, 2009, 2010 and 2011 which compromised hydro-power generation, and livestock and food production. The damages associated with the 2010 and 2011 droughts led to a deficit of 2.8 trillion (2.8×10^{12}) Uganda shillings; an equivalent of US$ 1.2 billion (Department of Disaster Management, Office of the Prime Minister, 2012).

In Uganda, temperature increases are more consistent to the GCM projections than precipitation. Projections of changes in temperature may still not however reach the 5.8 °C projected (Houghton et al., 2001). Precipitation projections for Uganda show that for the period March, April, May, precipitation will increase by about 6.4 mm during 2071–2100; this is higher than the increase of 6.2 mm recorded during the period 1961–1990. Other seasons such as the, June, July, August

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and September, October, November still had higher mean daily precipitation during 1961–1990 than during 2071–2100. It can be diagnosed from these trends that precipitation will be improved for sowing and harvesting in the south of Uganda since the season, March, April, May covers the growing season months for maize in the south. In the north, projections for March, April and May show that, precipitation will only be good for sowing with the growing period affected negatively. It has been projected thatthere will be a rise in mean daily temperatures for March, April, May from 23.0 to 23.9 °C for the 1961–1990 and 2071–2100 periods respectively. June, July, August and September, October, November will also have higher 2071–2100 temperatures than 1961–1990 (Robock et al., 1993; Houghton et al., 2001; Ward and Lasage, 2009; McSweeney et al., 2010).

We selected maize (*Zea mays*) as our unit of analysis in this study for the following reasons: 1) it is among the most widely cultivated crops in the world (maize, wheat, rice, soybeans, barley, sorghum). It is affordable and most widely grown in most of Africa and Uganda (Lobell and Field, 2007; Challinor et al., 2010; Epule and Bryant, 2015). 2) in Uganda, maize is consumed as staple fermented dough, roasted, used as corn porridge or converted into 'corn beer', and 3) maize is produced primarily (~90%) by small-scale farmers (Poate, 1988; Mutai and Ward, 2000; Moss et al., 2010; Challinor, 2008; Epule et al., 2015). 4) Ugandan maize is also grown across the country in differing agro-climatic zones, requiring medium (500 mm/growing season month) to high (800 mm/growing season month) precipitation (Mutai and Ward, 2000; Moss et al., 2010). The district level, past and future national scale vulnerability of maize yields to droughts in Uganda is unclear because of rising temperatures and declining precipitation, they may have varying effects on yields (Duvick and Cassman, 1999; Kulcharik and Serbin, 2008). For instance, Ugandan maize performs well under temperatures of between 20 and 22 °C but decreases when temperatures rise to about 27 °C (Kaizzi, 2014).

Up to date, vulnerability studies have focused on the magnitude of precipitation deficits (meteorological drought) and temperature changes, (Mishra and Singh, 2010, 2011). However, small droughts may trigger larger crop losses when compared to large droughts due to differences in sensitivity and adaptive capacity at household to community and regional scales (Simelton et al., 2009). Existing approaches to assessing the vulnerability of agriculture to droughts emphasise projections of meteorological changes and associated crop failures without considering socio-economic proxies of sensitivity and adaptive capacity with biophysical determinants of the effects of droughts on crop yields (Simelton et al., 2009; Fraser, 2003, 2006; Comenetz and Caviedes, 2002; Green, 1993). In this context, we project the vulnerability of maize yields to droughts by computing exposure, sensitivity, and adaptive capacity for the period (1960–2014) (based on Epule et al., 2017) and project into the future (2015–2050) based on three future temperature change scenarios of 1.5 °C, 2.0 °C and 2.5 °C. The study also sets a way forward by suggesting policy options that should be included when designing land use for agricultural purposes in the face of the changes projected by this study.

2. Methods

2.1. Key concepts: vulnerability, sensitivity, exposure and adaptive capacity and data sources and analysis

In 2013 Uganda had a population of ~36 million people (Mubiru and Banda, 2012). The mean annual precipitation ranges between 800 mm–1500 mm. In the south of the country precipitation is bi-modal (March–May and September–November) and uni-modal in the north (April–October) (Farley and Farmer, 2013; Government of Uganda, Ministry of Water and Environment, 2008). Temperature variations are very minimal across the country (Moss et al., 2010; Farley and Farmer, 2013). The analysis was done at both national and site scale. The site scale analysis were performed to give an understanding of the differences between the north and the south in terms of vulnerability. Ten sites/districts were selected for this analysis because of the availability of data on: maize yield, precipitation and literacy and poverty rates (socio-economic proxies) and are consistent with weather station data availability. The vulnerability approach used here builds upon other vulnerability indices such as the Notre Dame Global Adaptation Index (ND-GAIN) (Chen et al., 2015), the crop-drought indicator (Simelton et al., 2009), and the water-poverty index (Sullivan, 2002; Adger et al., 2004; Eriksen and Kelly, 2007), but is notable in that it is used specifically for application in an African maize farming context.

Vulnerability can be defined as the degree to which a system is susceptible to and unable to cope and recover from the negative adverse effects of climate change as well as extreme weather events (IPCC, 2007; Sherman et al., 2016). The concept of vulnerability to global change processes is context specific and involves cultural, political, socio-economic drivers that interact with global change to render some households, regions, communities, countries more or less susceptible to climate change (IPCC, 2007; McCarthy et al., 2001; O'Brien et al., 2007; Government of Uganda, Ministry of Water and Environment, 2008; Simelton et al., 2009; Challinor et al., 2010; Ford et al., 2013; Füssel, 2009; Sherman and Ford, 2013). Vulnerability is a function of: 1). the *sensitivity* of maize to droughts (Ford et al., 2010, 2013), 2). the level of *exposure* of maize to droughts (Ford et al., 2010, 2013) 3). the *adaptive capacity* of maize or ability to absorb the shocks caused by the decline in precipitation as well as the ability of farmers to adapt to changes (Ford and Smit, 2004; Ford et al., 2006; Smit and Wandel, 2006; Easterling et al., 2007; Nelson et al., 2007; Moss et al., 2010; Ford et al., 2013). In this study, we validate a sub-index for each of these components of vulnerability that incorporates agro-ecological, climatic, and socio-economic aspects of vulnerability to droughts, combining them together to test the predictability of a previous composite vulnerability index by Epule et al. (2017) (Eq. (1)): This enables us to verify the past, present (1960–2014) and future (2015–2050) vulnerability of maize yields to droughts in Uganda. The equation used to compute vulnerability is as follows:

$$VU_{mi} = SE_{mi} + EX_{mi} - ADC_{mi} \tag{1}$$

where VU_{mi} is the maize yield vulnerability index, SE_{mi} is the maize yield sensitivity index, EX_{mi} is the maize yield exposure index and ADC_{mi} is the maize yield adaptive capacity index.

2.2. Sensitivity index

Sensitivity is the reductions in maize yields/harvest that are due to climate change, climate variations and extreme events (IPCC, 2009; Sherman et al., 2016; Ford et al., 2013, 2010). It can also be defined as the manifestations of a climatic stimulus such as a drought in an agricultural system. For the 10 districts, time series data from 1999 to 2011 on actual maize yields (tons/ha/year) were collected from the Global Yield Gap Atlas (Kaizzi, 2014). At the national scale, time series data from 1961 to 2014 on actual maize yields (hectograms/ha/year converted to tons/ha/year) were collected from FAOSTAT (FAO, 2016a). The time scales were based on the availability of data. The actual maize yield data were subjected to detrending by removing a linear model of the time series of the actual maize yield by dividing the projected linear trend by the actual linear trend (see Eq. (2)). Detrending is important because it helps remove the effects of increased technology, illustrates yearly maize yield variations as a result of precipitation, and reduces the effects of consistent reporting errors (Easterling et al., 2007; Lobell et al., 2007, 2011). Expected yields were estimated by using the trend line equation for a simple linear regression (Eq. (2)). The sensitivity index for maize yields was obtained by dividing the mean expected maize yields by the mean actual maize yields (Eq. (3)); this is similar to procedures used by Simelton et al. (2009) in their study in which they identified the socio-economic indicators associated with sensitivity and resilience to droughts for each of China's key grain crops. The higher the sensitivity index, the more significant the effects of droughts.

$$EXP_y = ax + b \tag{2}$$

where EXP_y is the expected maize yield, x is the year, a is the linear trend, b is the intercept when $EXP_y = ax$

$$SE_{mi} = \frac{EXP_y}{ACT_y} \tag{3}$$

where SE_{mi} is the maize yield sensitivity index, EXP_y is the mean expected maize yield, ACT_y is the mean actual maize yield.

It is also expected that due to the changes in temperature there will be changes in expected and actual maize yields. As such, for purposes of uniformity and accuracy, the expected and actual maize yields were also reduced by 5% for each scenario. This percentage is consistent with arguments that maize yields are likely to reduce in Uganda by 5% for every 0.5 °C increase in temperature (Kaizzi, 2014).

2.3. Exposure index

In this study exposure describes the extent and nature of the stimulus reflected in the magnitude, intensity and duration of the climatic stimulus and in this case the drought (IPCC, 2007; Ford et al., 2010, 2013; Sherman et al., 2016). Precipitation data were used to reflect the extent to which maize is exposed to droughts. Only the maize growing season precipitation data were collected. Spatial variations in the maize growing season occurs in Uganda. According to various maize crop calendars (Sacks et al., 2010; Global Yield Gap Atlas, 2013; FAO, 2016b), the south of Uganda has bi-modal maize growing seasons. The first maize growing season begins with sowing in February and March, growing in April and May while harvesting occurs in June and July. The second maize growing season begins with sowing in September and October, growing in November and harvesting in December.

The north has a uni-modal or single growing season. Sowing occurs in April and May, growing in June and July and harvesting in August and September. For the national scale analysis, the mean short and long term growing season precipitation time series data from 1961 to 2014 and 1941–2014 respectively were obtained from the climate portal of the World Bank Group (2016). This data were validated by averaging over the maize growing months for each 5′ × 5′ grid for Uganda from the Global Crop Calendar Dataset (Sacks et al., 2010). For the 10 sites, mean short and long term growing season precipitation from 1999 to 2011 and 1960–2012 respectively were also obtained from the climate portal of the World Bank Group (2016). The exposure index was computed by dividing the mean long term maize growing season precipitation by the mean short term maize growing season precipitation (Eqs. (4) and (5)); similar to the procedures used in other studies (Simelton et al., 2009; Fraser, 2006, 2007; Epule et al., 2017). Only precipitation data were used for the district/site level exposure analysis because precipitation is the most important agro-climatic variable in Uganda (Sivakumar et al., 2005). The higher the exposure index, the more significant the effects of the droughts on maize yields. However, for the national scale analysis that depict the past, present (1960–2014) and future vulnerability (2015–2050) both precipitation and temperature data were used. The mean long term growing season temperatures from 1941 to 2014 and mean short term growing season temperatures from 1961 to 2014 obtained from the climate portal of the World Bank Group (2016) and used to compute the exposure index based on temperatures (Eq. (6)).

$$EX_{mir} = \frac{\mu LT_{mgsppt\,(1960to2012)}}{\mu ST_{mgsppt\,(1999to2011)}} \tag{4}$$

$\mu LT_{mgsppt\,(1960to2012)}$

$$EX_{mi\,ns} = \frac{\mu LT_{mgsppt\,(1941to2014)}}{\mu ST_{mgsppt\,(1961to2014)}} \tag{5}$$

where EX_{mi_ns} is the maize yield exposure index at a national scale, $\mu LT_{mgsppt\,(1941to2014)}$ is the mean long term maize growing season precipitation from 1941 to 2014 at a national scale, $\mu ST_{mgsppt\,(1961to2014)}$ is the mean short term maize growing season precipitation from 1961 to 2014 at a national scale.

$$EX_{mi\,nst} = \frac{\mu LT_{mgst\,(1941to2014)}}{\mu ST_{mgst\,(1961to2014)}} \tag{6}$$

where EX_{mi_nst} is the maize yield exposure index at a national scale based on temperature data, $\mu LT_{mgst\,(1941to2014)}$is the mean long term maize growing season temperature from 1941 to 2014 at a national scale, μST_{mgst}(1961 to 2014) is the mean short term maize growing season temperature from 1961 to 2014 at a national scale.

To estimate the level of exposure for the future period (2015–2050) temperature data were obtained from the climate portal of the World Bank Group (2016). However, the temperature data were subjected to three possible changes in temperature which include (1.5 °C increase in temperature, 2.0 °C increase in temperature and 2.5 °C increase in temperature). The objective here was to verify how different scenarios with respect to changes in temperature do affect exposure and subsequently, vulnerability. Eq. (7) was used as stated below:

$$EX_{mi\,nst} = \frac{\mu LT_{mgst\,(2015to2050)}}{\mu ST_{mgst\,(2025to2050)}} \tag{7}$$

where $\mathrm{EX}_{\mathrm{mi\_nst}}$ is the maize yield exposure index at a national scale based on temperature data, $\mu LT_{mgst\,(2015to2050)}$ is the mean long term maize growing season temperature from 2015 to 2050 at a national scale, $\mu ST_{mgst\,(2025to2050)}$ is the mean short term maize growing season temperature from 2025 to 2050 at a national scale.

2.4. Adaptive capacity index

Adaptive capacity can be defined as the flexibility with which any system can adjust to changes. In the context of this paper, this refers to the ability of maize production systems to adjust to climate change, extreme events and climate variability as well as the ability to take advantage of the opportunities to cope with the consequences of climate change and variability (IPCC, 2007; Ford et al., 2010, 2013). The effects a drought might have on maize yields is often a function of the adaptive capacity of the maize types and the effects of the droughts, for example… Simelton et al. (2009) noted that small droughts might have more daunting effects on maize yields if the adaptive capacity is inadequate to adjust to such changes. Several socio-economic proxies have been suggested for use in indicator-based approaches for vulnerability assessment, including: literacy rates, poverty rates, safety nets and transportation (Hentschel et al., 2000; Alderman et al., 2001; Smit and Pilifosova, 2003; Bangladesh Bureau of Statistics, 2004; Benson et al., 2005; Minot et al., 2006a,b; Daniels, 2011).

In this study, adaptive capacity is represented by two previously used proxies which are: poverty (%) (Material asset) and literacy rates (%) (Human asset). Poverty rate refers to material than financial assets because; "…income poverty measures provide important but incomplete guidance to redress multidimensional poverty" (Alkire and Santos, 2010). For the period under study, the poverty rate data were collected from Daniels (2011). The literacy rate data were collected from the Uganda Bureau of Statistics,UBOS (2006).

Due to limited data availability on other proxies, only poverty and literacy rate data were used as proxies of adaptive capacity. Poverty reduction can trigger improvements in the literacy rates (human assets) and the spillover effects of this could be reflected in improved social connections, networks and safety nets (social assets), improved transport and route networks (physical assets), improved ownership of property (material assets), and improved disposable income (financial assets) and opportunities for people to sustainably utilise resources (natural assets). In Uganda, improvements in agriculture are considered to be at the center of economic growth (IFAD, 2012). Daniels (2011) and UBOS (2006), argue that poverty reduction among farming households will drive growth in other sectors in Uganda. In addition, ∼87% of Ugandans live in rural areas and about 30% of all rural people are still below the national poverty line. Therefore, reducing poverty through agriculture is the main avenue to developing other sectors (IFAD, 2012) (see Eq. (8)).

The projected changes in temperature based on the three scenarios outlined when computing the future exposure for the period 2015–2050 are likely to have effects on the proxies of adaptive capacity. Since increase temperatures are likely going to impact yields; it has been argued that the national poverty rate for the future period in Uganda will increase by 5% if agricultural productivity is not enhanced (Daniels, 2011); as such under the current circumstances of temperature increase, poverty rates will increase from 24.5% during the past period to 29.5%, 34.5% and 39.5% based on temperature increases of 1.5 °C, 2.0 °C and 2.5 °C respectively for the future period. The literacy rate on the other hand is not extremely tied to future temperature change projections and as such for the future period we based our estimates on the arguments made by the Ugandan government that literacy rates are likely to increase by 5% (UBOS, 2006) from 69.6% in the past to 74.6% 79.6% and 84.6% based on the three projected temperature change scenarios respectively.

$$ADC_{mi} = \left(\frac{10^2 - P_r}{10^2}\right) + \left(\frac{L_r}{10^2}\right) \tag{8}$$

where ADC_{mi} is the maize yield adaptive capacity index, P_r is the poverty rate (%), L_r is the literacy rate (%).

3. Results

Based on both precipitation and temperature data inputs and at the national scale for the period (1960–2014) a vulnerability index of 0.6 (high) is observed. The sensitivity, exposure and adaptive capacity indices are 1.06 (High), 0.99 (High) and 1.45 (High) respectively (Table 1) (for a summary of the scale range used to categorize the indices see Fig. 2) (Epule et al., 2017). It can be observed that the degree of vulnerability, sensitivity, and exposure are high. The Adaptive capacity index is also high at the national scale due to low vulnerability. The latter is associated with an increase in adaptation efforts at the country level; however, it is inferior to those observed in the south and superior to those in the north.

As concerns the indices for the future period (2015–2050) and based on three temperature change scenarios of 1.5° C, 2.0° C and 2.5° C respectively the results show that as temperature increases vulnerability will increase progressively from 0.54 when temperatures rise by 1.5 °C, to 0.70 when temperature rise by 2.0 °C and to 1.54 when temperatures rise by 2.5 °C. Grossomodo, it can be said that the projections of increase temperature in Uganda up to 2050 will enhance the vulnerability of maize yields to droughts (Table 2 and Fig. 1). Another index that is likely to be very sensitive to the changes in temperature is the sensitivity index, it changes from 1.09 at 1.5 °C to 1.16 at 2.0 °C and finally increases to 2.0 at 2.5 °C. The exposure and adaptive capacity indices are the same for all the three scenarios; this is similar to what was observed during the 1960–2014 period. The overall conclusion is that when exposure and adaptive capacity do not change and temperature and sensitivity increase, the maize yields are still more vulnerable to droughts (Table 2 and Fig. 1).

Table 1
National scale indices of vulnerability of maize yields to droughts in Uganda based on precipitation and temperature data for the period 1960–2014.
Source: Adapted with permission from: Epule et al. (2017).

Indices	Precipitation	Temperature
Sensitivity index	1.06	1.06
Exposure index	0.99	0.99
Adaptive capacity index	1.45	1.45
Vulnerability index	0.60	0.60

Table 2
National scale indices of vulnerability of maize yields to droughts in Uganda based on future temperature changes from 2015 to 2050.

Indices	1.5 °C	2.0 °C	2.5 °C
Sensitivity index	1.09	1.16	2.0
Exposure index	0.99	0.99	0.99
Adaptive capacity index	1.45	1.45	1.45
Vulnerability index	0.54	0.70	1.54

As concerns the site level analysis for the period up to 2014, this study has observed that sites in the north have higher vulnerability indices when compared to the south (Fig. 2). The lowest vulnerability index recorded in the north is 0.58 in Kitgum and this is higher than the highest recorded in the south which is 0.27, recorded in Bulindi in the greater Masindi area (Fig. 2). Observations from all the other sites show that, maize yields are more vulnerable to droughts in the north of Uganda than in the south. The exposure indices assume the same trajectory as the vulnerability indices as the lowest exposure index in the north is 0.67, recorded in Kitgum and it is higher than the highest in the south which is 0.59, recorded in Tororo (Fig. 2). The exception to the general observation seems to be the sensitivity indices with the lowest index in the north (0.9) lower than the highest in the south (1.02). The mean sensitivity index for all the 5 sites for both regions illustrates that the mean sensitivity index for both regions is 0.99. While sensitivity and vulnerability are different for the 1960–2014 and 2015–2050 periods of analysis, we observe increasing sensitivity and vulnerability of maize yields with each 0.5 °C of temperature increase during the future period. Exposure and adaptive capacity on the other hand do not change during both periods at both site and national scale.

Based on the site level analysis for the two periods extending up to 2014 and 2050 respectively, the highest adaptive capacity index in the north is the same for both periods and it is 1.21, recorded in Lira while in the south it is also the same for the two periods and the highest is 1.71, recorded in Tororo (Fig. 2). In general, all the sites in the south have higher adaptive capacity indices than those in the north. The latter observation is same as in the relationship between adaptive capacity on the one hand and sensitivity and exposure on the other hand. Adaptive capacity also varies with latitude; as we move towards the higher latitudes (north), adaptive capacity reduces while at lower latitudes (south), it is higher (Fig. 3d). For the national scale analysis, the adaptive capacity index is 1.45. It is higher than the records obtained in the north of the country but lower than those observed in the south of the country which are cumulatively higher with the highest adaptive capacity index in the south being 1.71 recorded in Tororo. Latitudinally, it has been observed that for all the sites in Uganda, when latitude increases the exposure, sensitivity and vulnerability increase while adaptive capacity reduces (Fig. 3a–d). It can thus be said that the higher the sensitivity the higher the vulnerability as is the case in the north of Uganda. Also, the lower the sensitivity the lower the exposure as is the case with maize yields in the south of Uganda. The higher the exposure, the higher the level of vulnerability. However, when vulnerability is high the adaptive capacity is low. However, it is worthy of mention that, while vulnerability and sensitivity will increase during the 2015–2050 period, exposure and adaptive capacity remain unchanged as by 2050 they still assume the trends that were recorded in the 1960–2014 period (Fig. 3a-d).

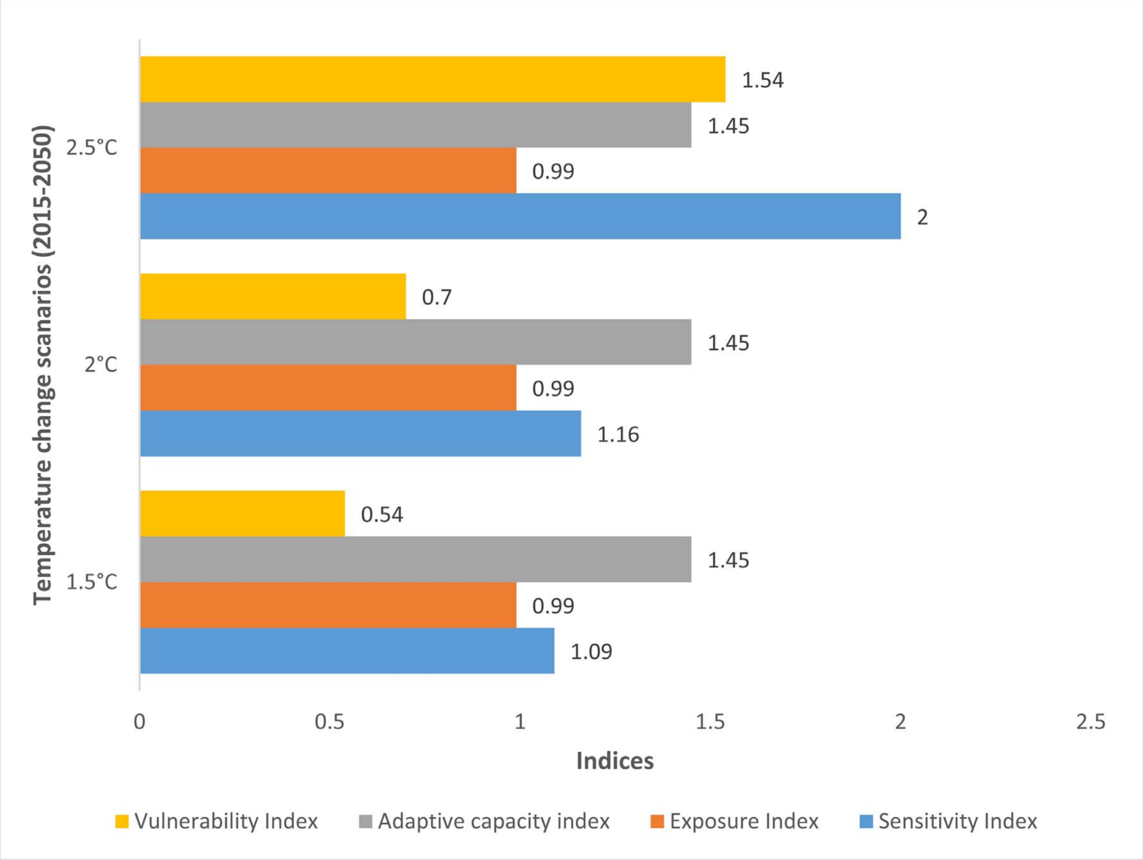

Fig. 1. National scale indices of vulnerability of maize yields to droughts in Uganda based on future temperature changes up to 2050 based on three temperature change scenarios.

4. Discussion

From the national scale analysis, the period 2015–2050 is likely going to experience high levels of maize yield vulnerability to droughts if the assumed changes in temperature occur. This is evident as the national scale vulnerability indices for the future period tend to be higher than those recorded in the past. While the future temperature projections are based on likely temperature increases of 1.5 °C, 2.0 °C and 2.5 °C during the period 2015–2050, these results are worth looking into as they seem to be consistent with projections from other parts of Africa, Asia and Latin America that argue that increase 21st century temperatures will continue to render food production in vulnerable parts of the world more vulnerable to droughts (Lobell et al., 2007, 2011). In a related study Thomson et al. (2010) observe that future climate change is likely to have effects on future food security and temperature changes are likely among the most important climate change variables that will champion the said changes. This finding is important because it alerts all stakeholders on the possible outcomes of an already very bad situation. The idea that future generations are going to pay for the enormous footprints of the current generation is worrying as it does not only defeat the principle of intergenerational sustainability but also shows us that much action needs to be put in place in terms of agroforestry, deforestation monitoring, diversification of the livelihoods of farmers and forest and grassland communities as well as make the available information available to all stakeholders through training and the use of indigenous knowledge in climate change adaptation. Unless all stakeholders are considered and the top-down approach to policies is avoided, solutions risk landing mankind into a situation of inertia. Based on the projections of future vulnerability up to 2050, vulnerability and sensitivity seem to rise while exposure and adaptive capacity are constant. This can be explained by the fact that sensitivity and vulnerability are affected by changes in temperature and precipitation while exposure is more a reflection of the changes in yield and during the period covered by the analysis maize yields have not been able to respond to changes in temperature and precipitation. During the period 1960–2014 sensitivity, exposure, adaptive capacity and vulnerability do not change under precipitation and temperature conditions. This can be explained by the fact that the changes in temperature during the period 1960–2014 does not bring any new changes to the observations obtained under precipitation conditions. Sensitivity is the only index that is computed based on precipitation and temperature data; the others: exposure is based on maize yield data, adaptive capacity uses socio-economic proxies while vulnerability is based on all the indices put together.

The result that vulnerability, exposure and sensitivity to droughts tends to increase towards the north of Uganda while adaptive capacity decreases is consistent with several studies (Tarhule, 2005; Nicholson et al., 1998; Zeng, 2003; Wang et al., 2005; Peng et al., 2011; Epule et al., 2014). An inverse relationship between latitude and precipitation in the Sahel has also been reported by (Faure and Gac, 1981Nicholson et al., 1998; Wang et al., 2005; Epule et al., 2014). According to a study that analysed the spatial patterns of droughts and tree mortality in Canada between 1960 and 2000, higher temperatures and lower precipitation levels were recorded above latitude 54 °C north while lower temperatures and higher precipitation levels recorded towards lower latitudes and were responsible for increase tree mortality (51–54° and < 51° north) (Peng et al., 2011). The spatial pattern of vulnerability recorded in Uganda can be explained by the fact that in the south of Uganda precipitation is bi-modal (March–May and September–November) and uni-modal in the north (April–October) (Sivakumar et al., 2005; Government of Uganda, Ministry of Water and Environment, 2008; Farley and Farmer, 2013). The low levels of precipitation recorded in the north can be used to explain the high level of maize yield vulnerability. The spatial variations and distribution of precipita-

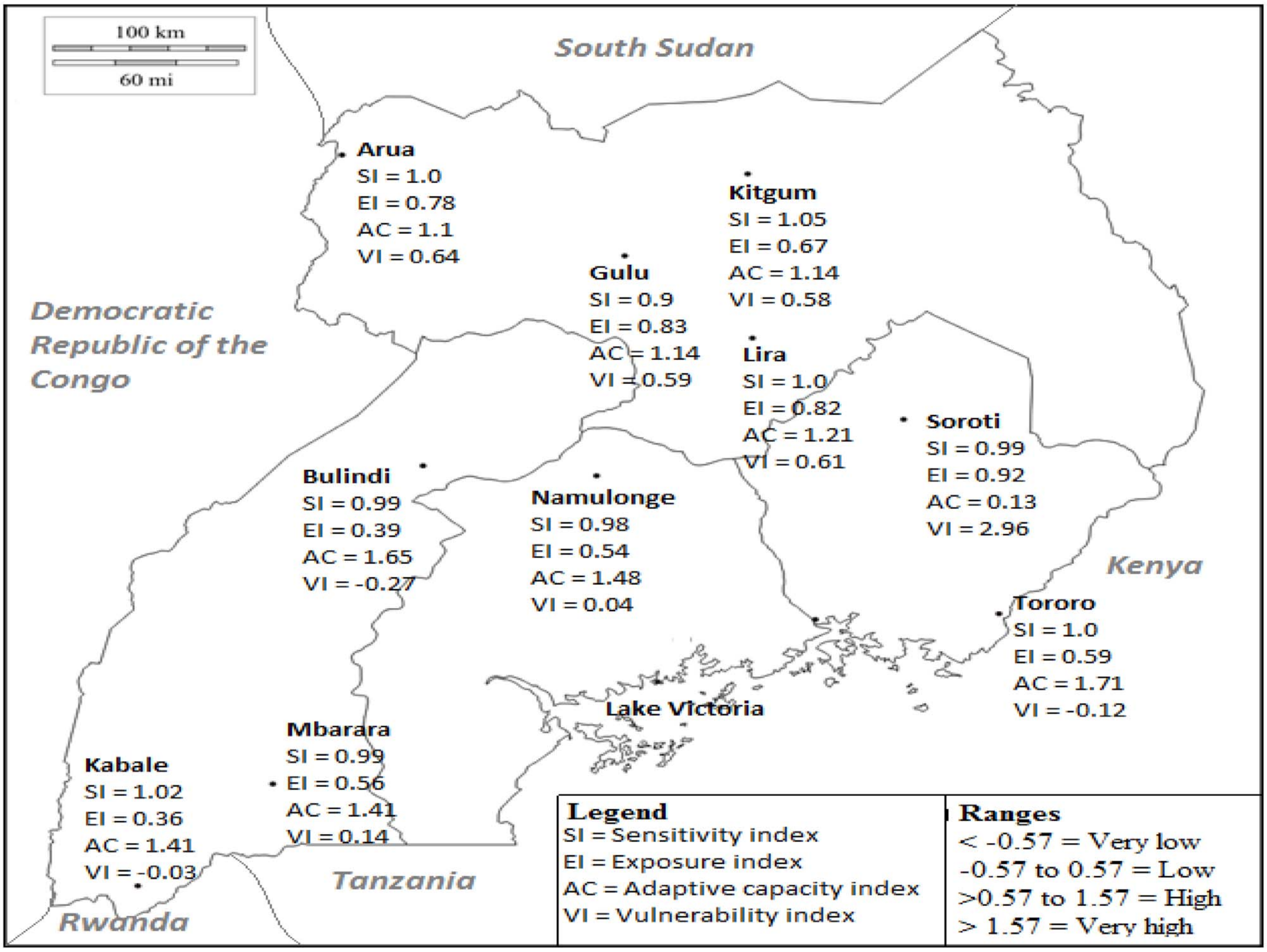

Fig. 2. Spatial pattern of crop yield sensitivity, exposure, adaptive capacity and vulnerability indices for various sites in Uganda from 1960 to 2014.
Source: Adapted with permission from Epule et al. (2017)

tion can be explained by variations in sea surface temperatures in the distant tropical pacific and Indian oceans. The south also has lakes like Lake Victoria, Lake Albert and Lake Edwards which help in enhancing precipitation (Farley and Farmer, 2013).

Obviously, there are several other factors that play an important role in determining the spatial pattern of vulnerability to droughts in Uganda. The presence of fertile volcanic soils in western Uganda around Lake Edward with average productivity in the greater south can also explain the variations. Fertile clay soils are also found in the south west of the Nebbi district and around Jinja and central Uganda. Around the, "Fertile Crescent" some 40–48 km wide around Lake Victoria from Jinja to Masaka, deep red loams occur (Kaizzi, 2014, 2016). In the north, most of the districts ranging from Gulu, Kitgum, to Moroto and most of Kotido, Kumi and Soroti have mostly soils that are shallow, sandy with low productivity (Kaizzi, 2014, 2016). However, the south of Uganda also has patches of infertile soils such as the montane soils around the upper slopes of Mount Elgon and parts of western Uganda. The Singo Hills north of Lake Wamala in central Uganda are no exception. As such, it is observed that the influence of soils is restricted and should be handled with caution.

There also exist a lot of socio-economic disparities between the north and the south of Uganda that account for these observations. It has been argued that in 2010, the poverty rate in the north was 46.2% and higher than the 21.8% recorded in the south (Daniels, 2011). Poverty reduces access to resources as poor communities are unable to obtain inputs such as fertilizers, high yielding drought resistant maize varieties, and irrigation infrastructure (Benson et al., 2005). It has also been reported that the literacy rates in the south ranged between 63% and 75% while in the north they ranged between 60% and 63%; with a national average of 69.6% (UBOS, 2006). IFAD (2012) argues that small-holder farmers in northern Uganda lack: vehicles and roads to transport their produce, technological inputs to increase production and reduce pests, have limited access to financial services that can boost their incomes and expand production. Asserting that the north of Uganda is less wealthy than the south of the country is supported by IFAD (2012) in the argument that the government of Uganda depends on the agricultural sector to drive growth and contribute to poverty reduction in the north and all of Uganda. The findings above are consistent to those from other studies (Sen, 1981; Moser, 1998; Bangladesh Bureau of Statistics and United Nations World Food Programme, 2004; Brocks et al., 2005; Benson et al., 2005; Gbetibouo et al., 2010; Defiesta and Rapera, 2014). Vulnerability to droughts in South Africa is linked to the degree of socio-economic development; assets, whether financial, human, natural, physical and social do greatly affect the ability of a community to cope with climate change related problems (Sen, 1981; Moser, 1998; Bangladesh Bureau of Statistics and United Nations World Food Programme, 2004; Brocks et al., 2005; Benson et al., 2005; Gbetibouo et al., 2010; Defiesta and Rapera, 2014). Socially, Pretty (2003) argues that in the face of droughts, well connected households rely on their friends and families for sustenance. In high income countries, social safety nets are so strong that during hazards, shelter, food, clothing and even finances are provided. Financial assets such as savings, pensions, and credit facilities enhance a community's ability to absorb the shocks related to droughts (Scoones, 1998). A limitation of financial assets is that it tends to show higher rates of poverty than reality and it is hard to translate income

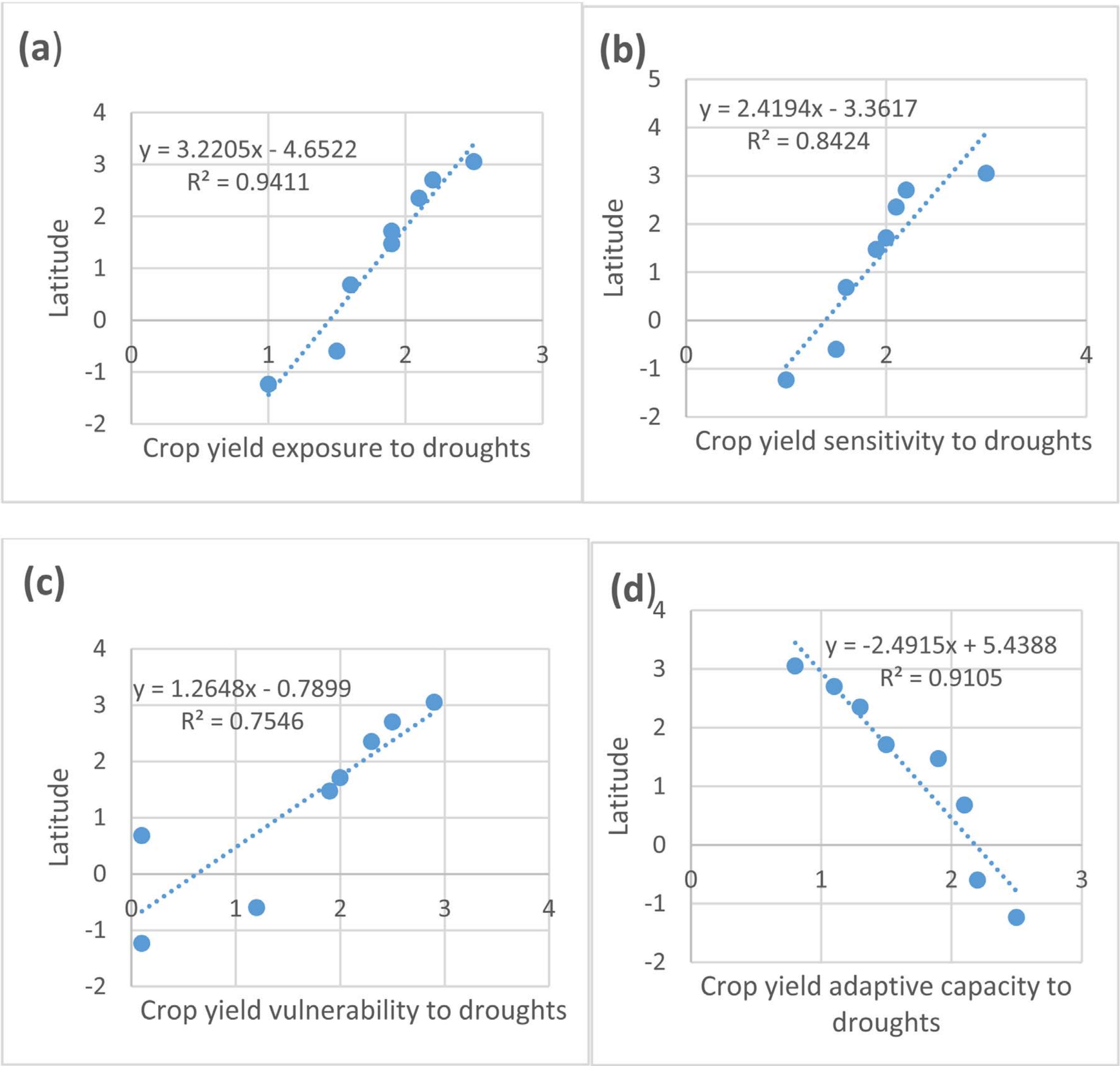

Fig. 3. Relationship between latitude and, (a) crop yield adaptive capacity to droughts, (b) crop yield exposure to droughts, (c) crop yield sensitivity to droughts and (d) crop yield vulnerability to droughts.

into health or educational expenses (Alkire and Santos, 2010). Physical assets such as farm to market roads may determine how fast a community responds to hazards as seen in the degree of rapidity with which relief or external support gets to the affected communities (Hentschel et al., 2000; Alderman et al., 2001; Adger et al., 2004; Epule et al., 2005). The level of education (human asset) does affect the ability to understand climate change related information (Rakodi, 1999).

Adaptive capacity is the most important of all the indices because we cannot determine the trajectory of climate in the future but we can determine how to respond to climate shocks through adaptations. The status of sensitivity and exposure will either remain the same, worsen off or reduce with adequate adaptations. What is key here is that more investments need to be made to enhance adaptive capacity which though a relatively new concept stands to determine the future of vulnerability. Notwithstanding the magnitude of a drought, adaptive capacity remains very important because small droughts can trigger heavy damages to crops when adaptive capacity is weak.

5. Conclusion and way forward

This study has shown that maize yields are more vulnerable to droughts in most of the northern sites in Uganda than in the south and nationally. In terms of future projections, Uganda is more likely to be more vulnerable to droughts if temperatures continue to increase. In terms of adaptive capacity, the sites in the south of the country have higher adaptive capacity. Latitudinally, it is observed that vulnerability, sensitivity and exposure increase with increase in latitude while adaptive capacity is higher at lower latitudes. This spatial pattern can be explained by a plethora of factors such as climatic, socio-economic and soil quality related factors. This index can be used to examine the vulnerability of other crops to various climatic stimuli and other hazards. The adaptive capacity sub-component of the index provides a statistical bases for the evaluation of adaptation to hazards. The vulnerability index successfully integrates socio-economic and biophysical variables and the results are consistent with previous studies.

The vulnerability index and suite of indices suggested by this study can definitely be used to explore the vulnerability of other crops and communities in developing countries to various global environmental change processes. The adaptive capacity sub-component of the index provides a statistical bases for the evaluation of adaptations based on proxies in developing countries to global environmental change processes and just like the main index itself, could be used in assessing vulnerability and adaptability in the context of other major global environmental change processes. Testing the applicability of these indices in other developing countries, the current requirements with respect to further research in the area of adaptation indices would be of great importance. However, the creation of a conceptual framework as well as detailed methodology and a global adaptation index that can monitor, track and evaluate the current status of adaptation progress in different parts of the world is another major gap in this line of research. From a land use policy perspective this study has observed that maize yields in Uganda are likely going to decline because of increase vulnerability, sensitivity, exposure and lower adaptive capacity. As a way forward, land use adjustment need to be put in place so such that existing agricultural systems can easily adapt to the expected changes in climate. Land use design must take into consideration the following options:

Agricultural land use policy should involve *water management* through *alternate wetting and drying* of the landscape. Most of the Sahel and sub-Saharan Africa (SSA) are often faced by intermittent periods of droughts or extensive periods of water shortages. As such, extensive water management is necessary to enhance crop production yields. One of the crops most affected by the availability of water in the Sahel and SSA is maize. As such, in the drier regions, irrigation should take place or water directed into fields to ensure growth of crops. However, care should be taken to avoid excessive flooding of the land that could lead to anaerobic conditions and poor crop performance.

One of the best ways of encouraging sustainable agricultural production in SSA is by encouraging *agroforestry* or the planting of crops and trees on the same farm. Participatory research has shown that agroforestry systems are not only aimed at carbon sequestration but ultimately they enhance crop yields and rehabilitate the landscape. This is because of the ability of trees to increase above ground biomass, provide litter and enhance soil organic content as well as enhance soil organic carbon and nitrogen which are very vital for crop yields. Globally, about 1.2 billion people are using agroforestry methods in their farms. In integrating trees into farms, the farmers have to be careful; the types of trees to be planted should be indigenous fruit trees that have implications on planting decisions which are also impacted by socio-cultural values, market, food and the medicinal value of trees. Examples of such trees may include: pawpaw, cocoa, coffee, avocado, mango, cashew and banana etc. These are trees that produce fruits that can be eaten and sold. Mixed cropping on the other hand involves the growing of crops and keeping of animals. A true opportunity for agroecology here is that the trees benefit from the droppings of the animals as manure while the wastes from the crops serve as food to the animals or are used to produce compost; a real opportunity for agroecology and diversification of livelihoods. The benefits of agroforestry and mixed farming include: sequestration of carbon dioxide, provision of food and fruits for the farmers and their livestock and wood for fuel, droppings from the animals serve as organic manure, mixed farming and agroforestry also help in the diversification of livelihoods by providing alternative sources of sustenance to the farmers, waste is avoided as the remains from the animals are used to fertilize the crops while the remains from the crops can be used for the production of compost as well as the feeding the animals; a real opportunity for agroecology.

In addition, *climate and land use information management* or *innovation and information diffusion* should be taken into consideration when designing agricultural land use policies. This strategy is very important because all the information made available through research is made available to the farmers. Various avenues through which this can be achieved include *media outlets, and cell phone companies* etc. Here, farmers could be provided with information related to changes in planting dates due to delayed or early rains, temperatures, the availability of better planting materials, the schedules of training seminars or in general innovations that could be of importance to the farmers. A major problem with most projects in Africa is that very often, ‘state of the art’ innovations made available through research are not often made available to the concerned farmers. So there is a missing linkage between research results and implementation at farm level. This process bridges this gap by suggesting that various media outlets and cell phone companies become involved in transmitting information to the farmers. The provision of such basic information such as changes in planting dates due to delayed rains could be very critical in determining crop yields. Governments have to ensure that media outlets and cell phone companies freely provide the required information to all owners of cells phones and viewers and listeners of television and radio channels. This way, the information gets to the farmers directly, on time and in simplified form.

Finally, *farmers' indigenous knowledge* should be involved in *land use policy design*. This is very important because the farmers that live in any region have a certain level of *indigenous knowledge* that is very vital in agricultural adaptation. In this case, policy makers, researchers etc. must speak to these farmers and consider their *indigenous knowledge in land use policy design* in the context of agriculture. *Indigenous knowledge* often involves undocumented practices that the farmers often use to cope with declining agricultural production or climate change without external influences or information. As such, the farmers have to be involved in the design and implementation phases of agricultural land use policies. This also involves participatory *learning and training* which creates a forum for the farmers to: provide their own knowledge on agriculture, learn about developments in climate smart agriculture. In addition, the farmers should be trained on how to interpret rainfall, temperature and other agriculture related information which otherwise remains remote to their understanding. One of the goals of climate mart agriculture is to reduce poverty and increase farm incomes.

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