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

Terence Epule Epule[a,*], James D. Ford[a], Shuaib Lwasa[b]

[a] Department of Geography, McGill University, 805 Sherbrooke St. W., Burnside Hall 614, Montreal, Quebec, H3A 0B9, Canada
[b] Department of Geography, Makerere University, P.O. Box 7062 Kampala, 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

* Corresponding author.
E-mail addresses: terence.epule@mail.mcgill.ca (T.E. Epule), james.ford@mcgill.ca (J.D. Ford), shuaiblwasa@gmail.com (S. Lwasa).

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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