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Vulnerability of maize yields to droughts in Uganda

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Abstract

Climate projections in sub-Sahara Africa (SSA) forecast an increase in the intensity and frequency of droughts with implications for maize production. While studies have examined how maize might be affected at the continental level, there have been few national or sub-national studies of vulnerability. We develop a vulnerability index that combines sensitivity, exposure and adaptive capacity, and integrates agroecological, climatic, and socio-economic variables, to evaluate the spatial pattern of maize yield vulnerability to droughts in Uganda. The results show that maize yields in the north of Uganda are more vulnerable to droughts than in the south and nationally. Adaptive capacity is higher in the south of the country than in the north.

Keywords: Uganda, Vulnerability, Sensitivity, Exposure, Adaptive Capacity, Droughts, Maize, Spatial pattern, Indices.

Introduction

The climate in most African countries south of the Sahara is warming, as seen in a 0.2-2.0 °C increase in temperatures during the past 35 years [1]. The rain-fed character of agriculture in Africa presents significant challenges [2-9], with small-scale farmers responsible for most of the production in sub-Saharan Africa (SSA) and are least equipped to adapt [10][11].The need for new integrative approaches that monitor resilience, adaptive capacity, vulnerability and the sensitivity of African agriculture to droughts is urgent [12, 13].

In Uganda, agriculture contributes about 20% to the gross domestic product (GDP) and a further 48% to export earnings [14]. Agriculture also employs about 73% of the population; about 4 million people depend on small-scale farming for their livelihoods [14], with poverty reduction contingent on improvements in agriculture [14, 15, 16]. Agricultural systems in Uganda are highly sensitive to climatic conditions, and major droughts in the last decade have had significant impacts, including: those of 2006 that resulted in higher food prices; those of 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 2.8×10^9 shillings (US$$1.2\times10^{12}$); 7% of Uganda's GDP [17].

Downscaled climate scenarios for Uganda illustrate that temperature increases are consistent to the GCM projections than precipitation. The rise in temperature may still not reach the 5.8°C projected [19]. Mean daily precipitation projections for Uganda show that for the period March, April, May, precipitation will rise by about 6.4mm during 2071-2100 from 6.2mm during 1961-1990. The other seasons, June, July, August and September, October, November will still have higher mean daily precipitation during 1961-1990 than during 2071-2100. These projections show 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, March, April, May the projected rise in precipitation will only be good for sowing with the growing period affected negatively. Temperature projections show that, there will be a rise in mean daily temperatures for March, April, May from 23.0 to 23.9C 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 [19-21].

Maize (*zea mays*) is among the most widely cultivated crops in the world (maize, wheat, rice, soybeans, barley, sorghum), and the most affordable and most widely grown in Africa and Uganda [22, [23, 24]. In Uganda, maize is a common staple food consumed as fermented dough, roasted, used as corn porridge or converted into beer, and is produced primarily (~90%) by small-scale farmers who are not often adequately adapted in the face of climate shocks [15, 27, 28][23, 24]. The spatial pattern of vulnerability of maize yields to droughts in Uganda is unclear, however, because rising temperatures and declining precipitation may have varying effects on yields [25, 26]. For instance, Ugandan maize performs well under temperatures of between 20-22°C but decreases when temperatures rise to about 27°C [14]. Ugandan maize is also grown across the country in differing agro-climatic zones, requiring medium (500mm/growing season month) to high (800mm/growing season month) precipitation.

In assessing the vulnerability of a crop to droughts, the general scholarship has focused on the magnitude of precipitation deficit (meteorological drought) and temperature changes [29, 30]. Yet small droughts may trigger larger crop losses while larger droughts may not have such effects due to differences in sensitivity and adaptive capacity at household to community to regional scales [31]. Indeed, many modeling approaches to assessing the vulnerability of agricultural systems focus only on projecting changes in meteorological conditions and associated crop impacts, failing to account for socio-economic determinants of vulnerability [31][32, 33, 34, 35]. In this context, we develop a vulnerability index that captures both exposure, sensitivity, and adaptive capacity, using the index to assess the spatial pattern of vulnerability of maize yields to droughts in Uganda.

Methods

Study area

Uganda is located in East Africa and in 2013 had a population of ~36 million [36]. This humid equatorial country has mean annual precipitation between 800mm to 1500mm: in the south precipitation is bi-modal (March-May and September-November) and uni-modal in the north (April-October) [37, 38]. Temperature varies little across the nation; for this reason this study used precipitation [28, 37]. Table 1 represents the 10 districts. These sites were selected because: they have data on maize yield, precipitation and the proxy socio-economic variables such as literacy and poverty rates, they are located either in the north or the south of the country, they are host to maize farms, they have more than 60% of their population involved in agriculture, 90% of the maize farms are owned by small-scale farmers, and the sites are representative of the region in which they are found, for example, the sites in the north have a uni-modal maize growing season while those in the south have a bi-modal.

Table 1: Locational coordinates and altitude of the 10 districts under investigation

District	Crop	Longitude	Latitude	Elevation (m)
North				
Arua	Rainfed maize	30.91	3.05	1211
Gulu	Rainfed maize	32.28	2.78	1105
Kitgum	Rainfed maize	32.88	3.27	953
Lira	Rainfed maize	32.93	2.35	1091
Soroti	Rainfed maize	33.61	1.71	1123
South				
Kabale	Rainfed maize	30.01	-1.23	1869
Mbarara	Rainfed maize	30.68	-0.6	1402
Tororo	Rainfed maize	34.16	0.68	1171
Bulindi	Rainfed maize	31.44	1.47	1209
Namulonge	Rainfed maize	32.61	0.52	1160

Methodology

Vulnerability to climate change is context specific and entails cultural, political, socio-economic drivers that interact with climate to make some households, regions, communities, countries more or less susceptible to climate change [31]. Consistent with the general vulnerability scholarship [8, 10, 38, 39, 40, 41, 42] vulnerability is here conceptualized as a function of: 1). the *sensitivity* of maize to droughts [8, 43], 2). the level of *exposure* of maize to droughts [8, 43] 3). the *adaptive* *capacity* of maize or ability to absorb the shocks created by the decline in precipitation [8, 28, 44, 45, 46, 47, 48]. In our approach, we develop 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 create a composite vulnerability index (equation 1) (Fig.1.):

$$VU_{mi} = SE_{mi} + EX_{mi} - ADC_{mi} \ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots.\ldots equation\ 1$$

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.

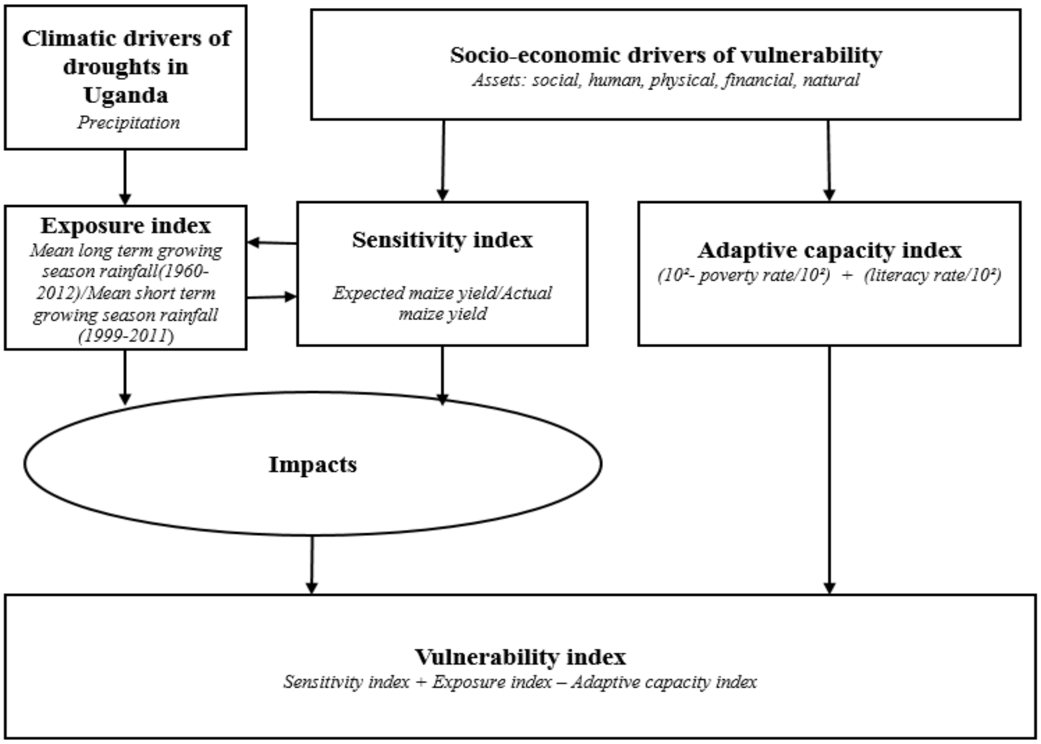

Fig.1. Theoretical framework for assessing vulnerability and summary of quantification procedure.

The approach builds upon other vulnerability indices including the Notre Dame Global Adaptation Index (ND-GAIN) [52], the crop-drought indicator [31], and the water-poverty index [55], but is notable in that is developed specifically for application in an African maize farming context.

Sensitivity index

The maize yield sensitivity index describes the reductions in harvest that are due to droughts. For the 10 sites, time series data from 1999 to 2011 on actual maize yields (tons/ha/year) were collected from the Global Crop Yield Atlas: http://www.yieldgap.org/glossary [14]. 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 (http://faostat3.fao.org/download/Q/QC/E [58]). The periods 1999 to 2011 and 1961 to 2014 were selected because of 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 equation 2). Detrending helps remove the repercussions of increased technology, illustrates yearly maize yield variations as a result of precipitation, and reduces the effects of consistent errors in reporting [44, 59, 60]. The expected yields were projected for each year by using the trend line equation for a simple linear regression (equation 2). The sensitivity index for maize yields was computed by dividing the mean expected maize yields by the mean actual maize yields (equation 3); similar procedures are used by Simelton et al. [31] in their ..[briefly describe their work]. The higher the sensitivity index, the more significant the effects of droughts on maize yields.

$$EXP_y = ax + b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, equation \; 2$$

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

$$SE_{mi} = \frac{EXP_y}{ACT_y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, equation \; 3$$

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.

Exposure index

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 [61, 62, 63], 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 (Fig.2.). For the national scale analysis, the mean short and long term growing season precipitation time series data from 1961 to 2014 and 1941 to 2014 respectively were obtained from the climate portal of the World Bank Group (http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu

=historical) [64]. This data were validated by averaging over the maize growing months for each $5' \times 5'$ grid for Uganda from the Global Crop Calendar Dataset: (http://www.sage.wisc.edu/download/sack/crop_calendar.html) [61]. For the 10 sites, mean short and long term growing season precipitation from 1999 to 2011 and 1960 to 2012 respectively were also obtained from the climate portal of the World Bank Group: http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu =historical [64]. The exposure index was computed by dividing the mean long term maize growing season precipitation by the mean short term maize growing season precipitation (equations 4 and 5); similar to the procedures used in other studies [31, 33, 65]. Only precipitation data were used because precipitation is the most important agro-climatic variable in Uganda [66]. The higher the exposure index, the more significant the effects of the droughts on maize yields.

$$EX_{mir} = \frac{\mu LT_{mgsppt(1960\ to\ 2012)}}{\mu ST_{mgsppt(1999\ to\ 2011)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, equation\ 4$$

where EX_{mir} is the maize yield exposure index for the 10 sites, $\mu LT_{mgsppt(1960\ to\ 2012)}$ is the mean long term maize growing season precipitation from 1960 to 2012 for each of the 10 sites, $\mu ST_{mgsppt(1999\ to\ 2011)}$ is mean short term maize growing season precipitation from 1999 to 2011 for each of the 10 sites.

$$EX_{mi\_ns} = \frac{\mu LT_{mgsppt(1941\ to\ 2014)}}{\mu ST_{mgsppt(1961\ to\ 2014)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, equation\ 5$$

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

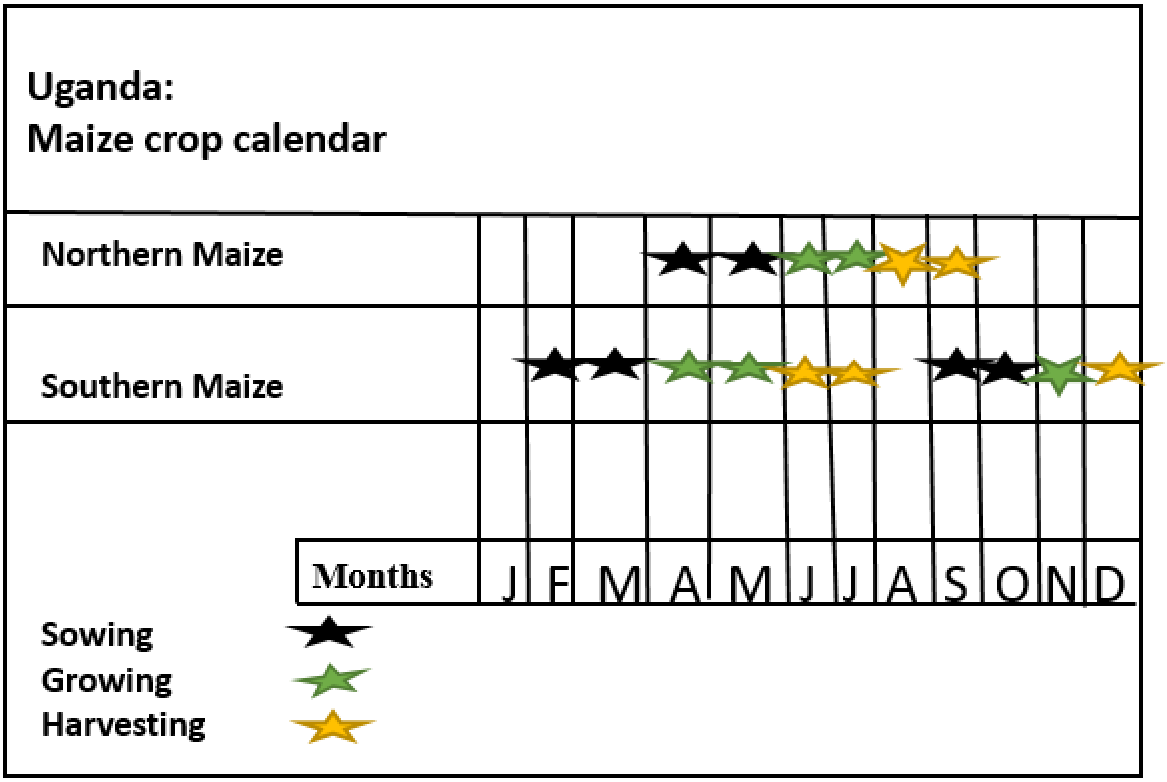

Fig 2: Maize crop calendar for Uganda. Source: Authors conceptualization inspired from; FAO, (2016): http://www.fao.org/giews/countrybrief/country.jsp?code=UGA.

Adaptive capacity index

The magnitude of the effects a drought has on maize yields is often determined by the adaptive capacity of farmers to manage the effects of drought through, for example, ….. Simelton et al. [31] observed that small droughts might have relatively large effects on maize yields in the face of inadequate adaptive capacity and vice versa because high adaptive capacity lowers vulnerability. A variety of socio-economic proxies have been suggested for use in indicator-based approaches for vulnerability assessment, including …… [67-73].

To assess the adaptive capacity of maize, this study used two socio-economic proxies: poverty (%) (Material asset) and literacy rates (%) (Human asset). Poverty rate in the context of this study refers to material than financial assets because; "…income poverty measures provide important but incomplete guidance to redress multidimensional poverty" [74]. Income shows higher rates of poverty than reality and not all households have the ability to translate income into health or educational expenses [74]. The poverty rate data were collected based on indicators such as: size of household, type of floor, source of water, type of toilet, presence or absence of electricity, and were obtained from Daniels [69]. The literacy rate data were taken from the Uganda Bureau of Statistics (UBOS) [75].

Poverty and literacy rates were selected as the main socio-economic proxies because of limited data on the other potential proxies such as … and also because these two proxies capture and impact all other proxies. For example, poverty reduction can lead to 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). Opportunities for people to sustainably utilise resources (natural assets) may occur. The Government of Uganda depends on growth in the agriculture sector to trigger economic growth [16]. According to Daniels [69] and UBOS [75], 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 (10 million men, women and children) are still below the national poverty line. Reducing poverty through agriculture is the main avenue to developing other sectors [16]. When poverty rates are high, the farmers tend to have low adaptive capacity because, they are unable to either purchase drought resistant maize seeds, unable to invest in: irrigation, fertilizers and other farm inputs. Low literacy rates will mean low adaptive capacity since the farmers might be unable to interpret and understand communications such as changes in planting dates, availability of drought resistant varieties and to secure other sources of livelihood sustenance (see equation 6).

$$ADC_{mi} = \left(\frac{10^2 - P_r}{10^2}\right) + \left(\frac{L_r}{10^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation } 6$$

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

Results

For the national level, a vulnerability index of 0.6 (high) is recorded. The sensitivity, exposure and adaptive capacity indices are 1.06 (High), 0.99 (High) and 1.45 (High) respectively (Table 2). It can be said that the degree of vulnerability, sensitivity, and exposure are high. The Adaptive capacity index is also high at the national scale; however, it is inferior to those observed in the south and superior to those in the north.

Tables 2: National scale estimates of vulnerability of maize yield to droughts in Uganda

Parameters	**Estimates**

Sensitivity index	1.06
Exposure index	0.99
Adaptive capacity index	1.45
Vulnerability index	0.6

The sites in the north have higher vulnerability indices when compared to the south (Table 1 and Fig 3). 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 (Table 1 and Fig.3.). The exposure indices assume the same trajectory as the vulnerability indices. 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.3.). The sensitivity indices seem to be an exception in which the lowest index in the north (0.9) is lower than the highest in the south (1.02). However, the mean exposure index for both regions is 0.99. All the vulnerability indices in the south are lower than the 0.6 recorded at the national scale while those recorded in the north either spiral around the national average of 0.6 and peak to 2.96 in Soroti. The exposure indices are higher nationally as the 0.99 recorded at the national level is higher than those obtained in the north and the south; those recorded in the north are higher than those of the south. The site level sensitivity indices for the north and south of Uganda are very close to the national average of 1.06; but generally lower as the mean for both the north and the south are 0.99.

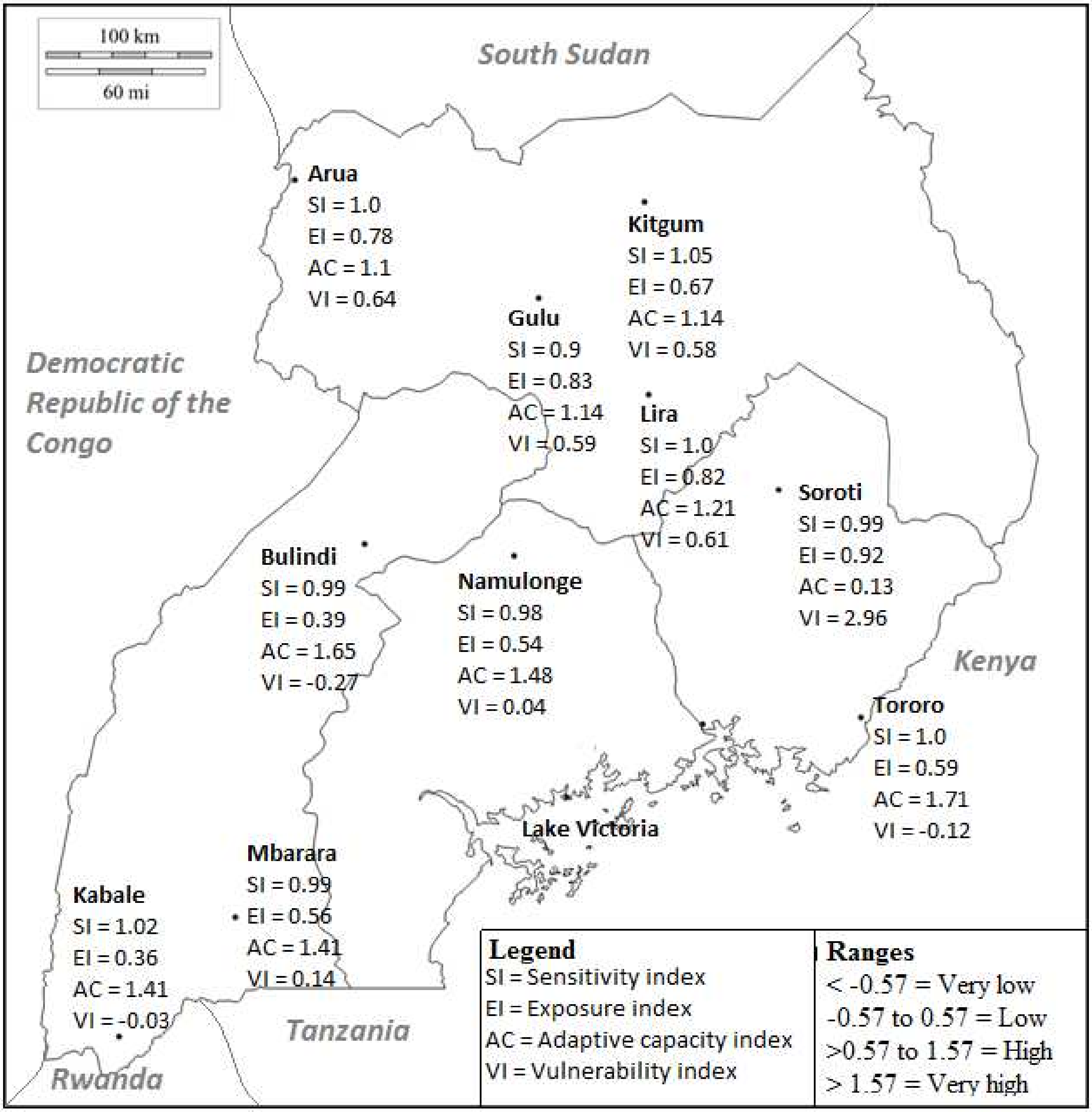

Fig 3. The spatial pattern of crop yield sensitivity, exposure, adaptive capacity and vulnerability indices for various stations in Uganda. Source: Based on findings from this study.

It is observed that higher sensitivity indices are associated with higher vulnerability indices as is the case with maize yields in the north of Uganda (Fig.4a). The coefficient of determination of about 0.91 depicts that, about 91% of the variations in vulnerability can be explained by the level of sensitivity of maize. Also, the higher the exposure, the higher the level of vulnerability. The coefficient of determination of 0.92 means that about 92% of the changes in vulnerability can be explained by the exposure (Fig.4b). As seen on Fig 5a, b and c, towards higher latitudes in Uganda

(North), the exposure, sensitivity and vulnerability of maize yields to droughts increases and vice versa.

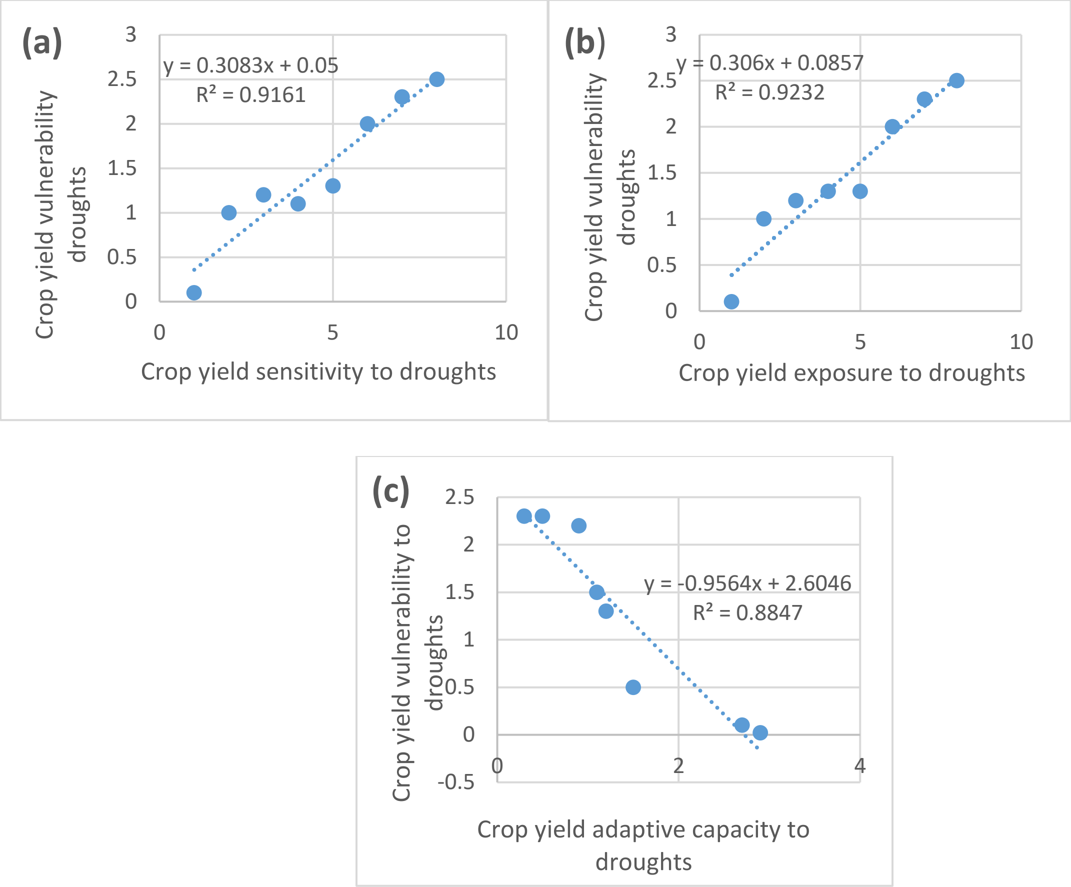

Fig 4. Relationship between crop yield vulnerability to droughts and, (a) crop yield sensitivity to droughts, (b) crop yield exposure to droughts and (c) crop yields adaptive capacity to droughts.

The highest adaptive capacity index in the north is 1.21, recorded in Lira while in the south, the highest is 1.71, recorded in Tororo (Fig.3.). In general, all the sites in the south have higher adaptive capacity indices than those in the north. When the adaptive capacity is high in the south, vulnerability is low (Fig.4c). The coefficient of determination of 0.88 shows that about 88% of the changes in vulnerability can be explained by the changes in adaptive capacity. The latter observation is same in the relationship between adaptive capacity on the one hand and sensitivity and exposure on the other hand. As we move towards the higher latitudes (north), adaptive capacity reduces while at lower latitudes (south), it is higher (Fig.5d). 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 south.

Adaptive capacity is the most important of all the indices because we cannot determine the way climate will behave but we can determine how to respond to climate shocks through adaptations.

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. Simelton et al. [31] also support this view when they observe that climate change studies should be based on adaptations being that the magnitude of a drought does not really matter if adaptations are adequate.

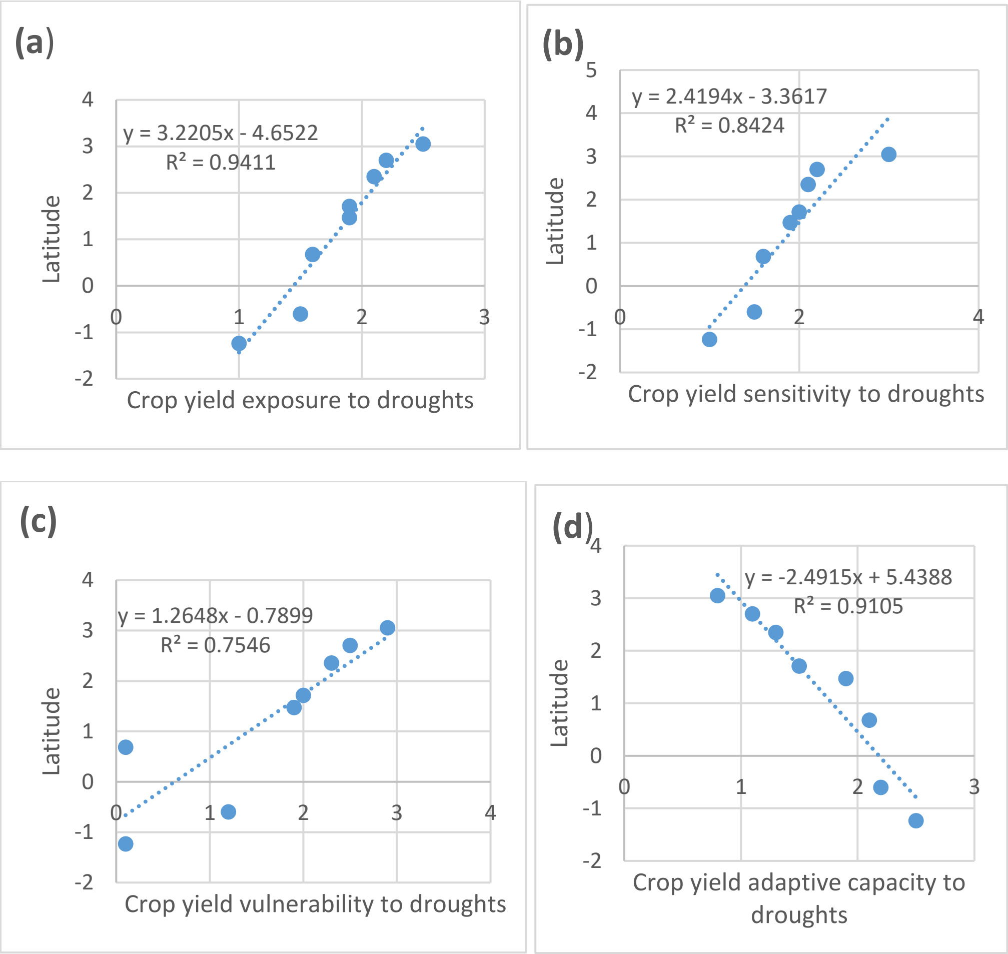

Fig 5. Relationship between latitude and, (a) crop yield adaptive capacity to droughts, (b) crop yield exposure to droughts, (c) crop yield sensitivity to droughts and (d) crop yield vulnerability to droughts.

Discussion

The argument that vulnerability, exposure and sensitivity to droughts increase towards the north of Uganda while adaptive capacity decreases is consistent with previous studies. There is an inverse relationship between latitude and precipitation in the Sahel [76, 77, 78]. This 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) [37, 38]. The low levels of precipitation recorded in the northern can be used to explain the high level of maize yield vulnerability. The spatial variations and distribution of precipitation 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 [37]. Findings by Thomson et al. [7] also highlight the importance of climate on food security in SSA.

The socio-economic differences between the north and the south of Uganda can explain the observations. Daniels [69] argued that in 2010, the poverty rate in the north was 46.2% and higher than the 21.8% recorded in the south. Poor people are unable to invest in inputs such as fertilizers, high yielding drought resistant maize varieties, and irrigation infrastructure. The UBOS [75], reported that the literacy rates in the south ranged between 63% and 75% while in the north they range between 60% and 63%; with a national average of 69.6%. It can be said that when poverty is high, literacy rates are often low and communities become more vulnerable to droughts because low education translates into reduced earning capacity, limited ability to comprehend early weather warnings and shifts in planting dates. IFAD [16] supports these assertions by noting 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. The assertion that the north of Uganda is the poorest region of the country is supported by IFAD [16] that argues that the government of Uganda depends on the agricultural sector to drive growth and contribute to poverty reduction.

The findings above are consistent to those from other studies. 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 [50, 51, 79]. Socially, Pretty [80] argues that in the face of droughts, well connected households rely on their friends and families for sustenance. In advanced 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 [81]. A limitation of financial assets is that it tends to show higher rates of poverty than reality and it is hard to translate income into health or educational expenses [74]. 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 [56, 82]. The level of education (human asset) does affect the ability to understand climate change related information [83].

The spatial distribution 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 [14, 84]. 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 [14, 84]. The south has patches of infertile soils such as the montane soils around the upper slopes of Mount Elgon and parts of western Uganda.

Conclusion

The results show that most of the northern sites in Uganda have higher vulnerability than the south and national average. In terms of adaptive capacity, the sites in the south of the country have higher adaptive capacity. 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 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.

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