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Vulnerability of Maize Yields to Droughts in Uganda

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Abstract: Climate projections in Sub-Saharan 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 that integrates agroecological, climatic and socio-economic variables to evaluate the national and 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. Maize yields also record higher levels of sensitivity and exposure in the north of Uganda than in the south. Latitudinally, it is observed that maize yields in Uganda tend to record higher levels of vulnerability, exposure and sensitivity towards higher latitudes, while in contrast, the adaptive capacity of maize yields is higher towards the lower latitudes. In addition to lower precipitation levels in the north of the country, these observations can also be explained by poor soil quality in most of the north and socio-economic proxies, such as, higher poverty and lower literacy rates in the north of Uganda.

Keywords: Uganda; vulnerability; sensitivity; exposure; adaptive capacity; droughts; maize; spatial pattern

1. 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 [1–9], with small-scale farmers responsible for most agricultural production in Sub-Saharan Africa (SSA) and 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] because the effects of droughts will be reflected in the degree of vulnerability, exposure, sensitivity and adaptive capacity of cropping systems [12–18].

In Uganda, agriculture contributes about 20% to the gross do mestic product (GDP), 48% to export earnings [19] and employs about 73% of the population. More than four million households depend on small-scale farming for their livelihoods [19], with poverty reduction contingent on improvements in agriculture [16,19,20]. Agricultural systems in Uganda are highly sensitive to climatic conditions, and major droughts in the last decade 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 (US$$1.2 \times 10^{9}$); or 7% of Uganda's GDP [21,22].

Downscaled climate scenarios for Uganda illustrate that temperature increases are more consistent to the GCM projections than precipitation. The rise in temperature may still not, however, reach the 5.8 °C projected [23]. Mean daily precipitation projections for Uganda show that for the period of March, April and 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 of 1961–1990. The other seasons, June, July, August and September, October, November, still had higher mean daily precipitation during 1961–1990 than projections for 2071–2100. These projections show that precipitation will be improved for sowing and harvesting in the south of Uganda since the season of March, April and May covers the growing season months for maize in the south. In the north, for March, April and 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 and 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 [23–26]. However, recent reports from the famine early warning systems network indicate that there has been an increase in seasonal mean temperature in many parts of Uganda, Ethiopia and Kenya. Regional climate models suggest drying over most parts of Uganda, Kenya and South Sudan in August and September by the end of the 21st century, all associated with a weakening Somali jet and Indian Ocean monsoon. Declines in surface water discharge in the Upper Nile Basin of Uganda have also been recorded. Projection of surface temperature changes over east Africa may approach 6 °C by 2100 in an extreme scenario, while more conservative changes show increases just around the 2 °C mark. In the case of precipitation, projections show changes in the range of +20% or −20% by the year 2100 [1,23].

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 [10,27,28]. 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 [20,29–32]. The spatial pattern of vulnerability of maize yields to droughts in Uganda is unclear; however, because of rising temperatures and declining precipitation, they may have varying effects on yields [33,34]. For instance, Ugandan maize performs well under temperatures of between 20 and 22 °C, but decreases when temperatures rise to about 27 °C [19]. 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 [29,30]).

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 [35,36]. Yet, small droughts may trigger larger crop losses, while larger droughts may not have such effects due to differences in the sensitivity and adaptive capacity at the household to community to regional scales [14]. 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 integrate socio-economic proxies of sensitivity and adaptive capacity with biophysical determinants of the effects of droughts on crop yields [14–18]. In this context, we develop a vulnerability index that captures exposure, sensitivity and adaptive capacity, using the index to assess the national and spatial pattern of vulnerability of maize yields to droughts in Uganda.

The decade 1975–1985 witnessed one of the most ravaging droughts in the history of Africa in general and the Sahel in particular. Though the debates on the causes of the droughts have been very intense and controversial, the droughts are believed to have been triggered by wide-scale sea surface temperature changes, vegetation and land degradation, human-induced climate change and dust feedbacks [37–40]. Though the Sahel is endemic to droughts, recent history has that in terms of magnitude and scale, the droughts of the mid-1970s and early 1980s were among the most ravaging on the African continent in terms of the magnitude of food loss, environmental degradation and population movements inter alia [37]. Since the 1990s, the continent has witnessed a relative increase in precipitation and greenness as evidenced by normalized difference vegetation index (NDVI) [37].

2. Materials and Methods

2.1. Study Area

Uganda is located in East Africa and in 2013 had a population of ~36 million [30,41–43]. This humid equatorial country has mean annual precipitation between 800 mm and 1500 mm: in the south, precipitation is bi-modal (March–May and September–November) and uni-modal in the north (April–October) [41,42]. Temperature varies little across the nation [30,41]. This study is designed to reflect the vulnerability of maize yields to droughts at both the national and district level scales, with Table 1 representing the 10 districts that are covered by this study. These sites/districts 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 and weather stations; 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 one. The rationale of including both national- and district-level scales of analyses provides a baseline against which comparisons can be made. For example, even though interesting findings come out of the north-south comparisons, comparing the north-south scale findings with the national scale findings helps to further situate the district level in the context of what obtains at the national scale. In most cases, when district-scale observations are higher/lower than national-scale observations, the degree of intensity of vulnerability can be judged as either exceptionally high or exceptionally low relative to national-scale observations.

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-Hoima	Rainfed maize	31.44	1.47	1209
Namulonge	Rainfed maize	32.61	0.52	1160

2.2. Methodology

Vulnerability is the degree to which a system is susceptible to and unable to cope with the negative adverse effects of climate change, as well as extreme weather events [1,44]. Vulnerability to climate change is context specific and entails cultural, political and socio-economic drivers that interact with climate to make some households, regions, communities and countries more or less susceptible to climate change [14]. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which any given agricultural system is exposed (maize yields here) and the sensitivity and adaptive capacity of agricultural systems [1]. Consistent with the general vulnerability scholarship [8,10,42,45–48], vulnerability is here conceptualized as a function of: (1) the sensitivity of maize to droughts [8,49]; (2) the level of exposure of maize to droughts [8,49]; (3) the adaptive capacity of maize or the ability to absorb the shocks caused by the decline in precipitation, as well as the ability of farmers to adapt to changes [8,30,50–54]. 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)) (Figure 1):

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

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.

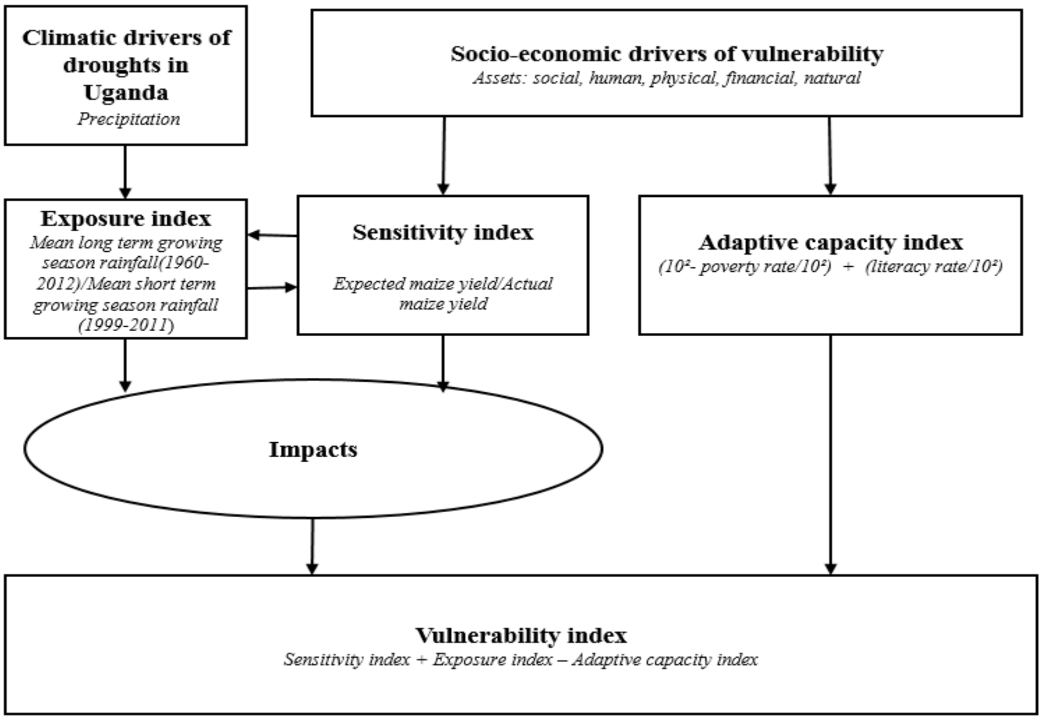

Figure 1. Theoretical framework for assessing vulnerability and the summary of the quantification procedure.

The approach builds upon other vulnerability indices, including the Notre Dame Global Adaptation Index (ND-GAIN) [55], the crop-drought indicator [14] and the water-poverty index [56,57], but is notable in that it is developed specifically for application in an African maize farming context.

2.3. Sensitivity Index

Sensitivity is defined as the reductions in maize yields/harvest that are due to climate change, climate variations and extreme events [44,49,58–60], or the manifestations of a climatic stimulus on cropping systems. For the 10 sites, time series data from 1999 to 2011 on actual maize yields (tons/ha/year) were collected from the Global Yield Gap Atlas [19]. 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 [61]. The periods 1999–2011 and 1961–2014 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 annual maize yield variations as a result of precipitation and reduces the effects of consistent errors in reporting [27,53,61]. 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 [13,14] 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 on maize yields.

$$EXP_y = ax + b \quad (2)$$

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

$$SE_{mi} = \frac{EXP_y}{ACT_y} \quad (3)$$

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

2.4. Exposure Index

Exposure in the context of this study describes the extent and nature of the stimulus reflected in the magnitude, intensity and duration of the drought [1,44,49]. Precipitation data were used to reflect the extent to which maize is exposed to droughts. Furthermore, precipitation data adequately reflects the drought situation in Uganda because precipitation varies greatly from one site to another. Therefore, to be able to understand the severity of the droughts, it becomes important to verify the short- and long-term growing season precipitation data. Temperature on the other remains an important climate change-related variable, but in Uganda, the temperatures are relatively high within and outside of the maize growing seasons; as such, to be able to understand the nature of the droughts, it is adequate to place emphasis on precipitation data. As such, the maize growing season precipitation data were collected. To be able to collect the appropriate maize growing season precipitation data, the maize growing seasons were identified across Uganda, from which spatial variations in the maize growing seasons were observed across Uganda. According to various maize crop calendars [62–64], 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 in the south of Uganda begins with sowing in September and October, growing in November and harvesting in December.

The north of Uganda 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 (Figure 2). For the national-scale analysis, the mean short- and long-term growing season precipitation time series data from 1961–2014 to 1941–2014 respectively were obtained from the climate portal of the World Bank Group [65]. The mean short-term growing season here represents the period from 1961 to 2014, while the mean long-term growing season represents the period from 1941 to 2014. These data were validated by averaging over the maize growing months for each 5′ × 5′ grid for Uganda from the Global Crop Calendar Dataset [62]. For the 10 sites, mean short- and long-term growing season precipitation from 1999 to 2011 and 1960–2012 respectively was also obtained from the climate portal of the World Bank Group [65]. The mean short-term growing season represents the period from 1999 to 2011, while the mean long-term growing season represents the period from 1960 to 2012. The exposure index was computed by dividing the mean long-term maize growing season precipitation data by the mean short-term maize growing season precipitation data (Equations (4) and (5)); these procedures are well established and have been used in other studies [14–16]. Mostly precipitation data were used for the district level analysis because precipitation is the most important agro-climatic variable in Uganda, as it varies from one region to another, whereas temperatures are almost the same all year round within and outside of the maize growing seasons; the mean average annual temperature is usually about 22 °C [65]. The first mean long-term growing season in the south begins with precipitation in February, while the mean short-term growing season begins with delayed rains, which may cause a shift in the start of rains to March or April. The second mean long-term growing season in the south begins with precipitation in September, while the second mean short-term growing season in the south may also be delayed to October or November (Figure 2). In the north, April usually ushers the beginning of rains in what has been termed the mean long-term growing reason, while when rains are delayed, there is a shift to May and July. The higher the exposure index, the more significant the effects of the droughts on maize yields. According to Redsteer et al. [66], several case studies around the world indicate that droughts can only be partly attributed to deficient or erratic precipitation, as droughts appear to be centered over several other drivers, including temperature. Others include variables, such as poverty, rural vulnerability and increased water demand due to urbanization, industrialization, soil conditions and governance systems inter alia [66]. It is for this reason that we decided to validate the assertion that temperatures do not change the results by using 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 [65] and used to compute the exposure index based on temperature data (Equation (6)).

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

where EX_{mir} is the maize yield exposure index for the site-level analysis (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 and $\mu ST_{mgsppt(1999\ to\ 2011)}$ is mean short-term maize growing season precipitation from 1999 to 2011 for each of the 10 sites.

$$EX_{mi\_nsp} = \frac{\mu LT_{mgsppt(1941\ to\ 2014)}}{\mu ST_{mgsppt(1961\ to\ 2014)}} \quad (5)$$

$$EX_{mi\_nst} = \frac{\mu LT_{mgst(1941\ to\ 2014)}}{\mu ST_{mgst(1961\ to\ 2014)}} \quad (6)$$

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

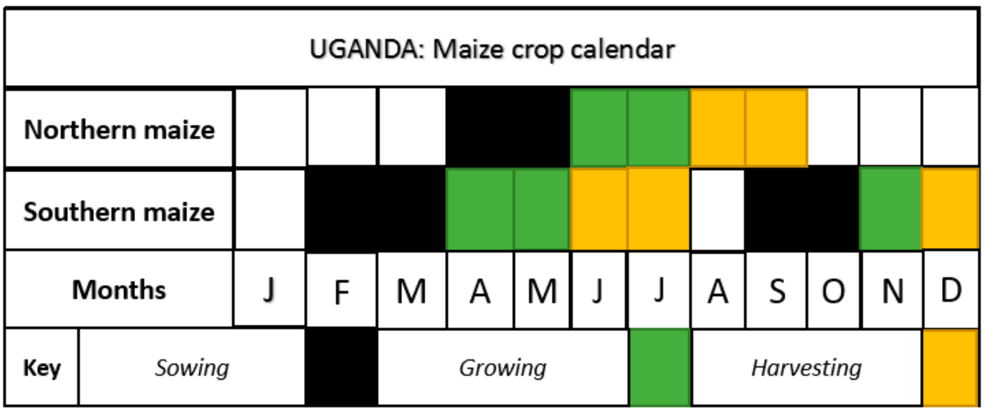

Figure 2. Maize crop calendar for Uganda. Source: the authors' conceptualization inspired by FAO [63].

2.5. Adaptive Capacity Index

Adaptive capacity is the ability of maize production systems to adjust to climate change, extreme events and climate variability and to take advantage of the opportunities to cope with the consequences of climate change and variability [1,8,49,67]. The magnitude of the effects a drought has on maize yields is often determined by the adaptive capacity of maize systems and types to manage the effects of droughts. Simelton et al. [14] 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: level of education and poverty, availability of safety nets and transportation systems [68–74].

To assess the adaptive capacity of maize farming, 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 rather than financial assets because; " . . . income poverty measures provide important but incomplete guidance to redress multidimensional poverty", Alkire and Santos [75]. Income shows higher rates of poverty than reality, and not all households have the ability to translate income into health or educational expenses [76]. The poverty rate data were collected based on indicators, such as: size of the household, type of floor, source of water, type of toilet, presence or absence of electricity; and were obtained from Daniels [76]. The literacy rate data were collected from [77].

Poverty and literacy rates were selected as the main socio-economic proxies because of limited data on the other potential proxies, such as route network, safety nets, natural resources (irrigation), etc., and also because these two proxies capture and impact most proxies. For example, poverty reduction can lead to improvements in the literacy rates (human assets), and the spillover effects of these could be reflected in improved transport and route networks (physical assets), improved ownership of property (material assets) and improved disposable income (financial assets), as well as the ability to harness rivers and streams for irrigation. Opportunities for people to sustainably utilize resources (natural assets, such as rivers) may emerge. It is important to however note that increased access to irrigation may help reduce the problem of the decline in precipitation. However, in Uganda, this is possible in the south, as most of the rivers in the south flow all year round, while those in the north are seasonal; this spatial variation in irrigation potential may often affect the feasibility of irrigation in many parts of the country. It is possible that reduced poverty rates in any region of the country can enhance access to irrigation through the creation of capital intensive boreholes and easy access to knowledge on new techniques of irrigation or even rainwater harvesting. As such, irrigation potential is linked to both the natural all year-round distribution of water resources and the ability of the people to harness these resources, which is also linked to poverty and literacy rates. Precipitation and access to irrigation also move in the same direction. A region with higher precipitation is likely going to have more water in its rivers, and this will enhance the feasibility of irrigation. However, even when rivers are available, the absence of knowledge and financial capabilities may render the irrigation potential worthless. The Government of Uganda depends on growth in the agriculture sector to trigger economic growth [22]. According to Daniels [76] and the Uganda Bureau of Statistics (UBOS) [77], 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 therefore a critical and the main avenue to developing other sectors [16,22]. When poverty rates are high, farmers tend to have low adaptive capacity because they are unable to either purchase drought-resistant maize seeds or 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, the availability of drought-resistant varieties and to secure other sources of livelihood sustenance (see Equation (7)).

$$ADC_{mi} = \left(\frac{10^2 - P_r}{10^2}\right) + \left(\frac{L_r}{10^2}\right) \quad (7)$$

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

3. Results

To assess the strength of the indices, the following ranges were used to categorize the indices: <−0.57 = very low, −0.57 to 0.57 = low, >0.57 to 1.57 = high, >1.57 = very high (see Figure 3). At the national level, a vulnerability index of 0.6 (high) based on exposure dependent on precipitation data is recorded. The parallel 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. However, when national-level exposure is computed based on temperature data, the results are exactly the same as when it is based on precipitation data. This is seen as the mean long-term growing season temperature (1941–2014) is 22.82911 °C, while the mean short-term growing season temperature (1961–2014) is 22.93344161 °C; this gives an exposure index of 0.99 (high), which is exactly the same when exposure is based on precipitation data. As such, the sensitivity and vulnerability indices are the same when exposure is based on precipitation data, as well as when it is based on temperature data. The adaptive capacity index is relatively also high at the national scale due to a lower vulnerability index. A lot of effort is being put in place to enhance resilience, and this involves the totality of adaptations for the entire country; however, it is inferior to those observed in the south and superior to those in the north.

From the perspective of sites, the sites in the north have higher vulnerability indices when compared to the south (Figure 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-Hoima (Figure 3). Considering observations from all of the other sites, it can be said 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. 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 (Figure 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, if we compute the mean sensitivity index for all five sites for both regions, it is observed that the mean sensitivity index for both regions is 0.99. Overall, it can be said that maize yields in the north of Uganda are overwhelmingly more vulnerable and more exposed to droughts than in the south. All of 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 at 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 is 0.99.

Table 2. National-scale estimates of the vulnerability of maize yield to droughts in Uganda based on precipitation and temperature data.

Parameters	Precipitation Estimates	Temperature Estimates
Sensitivity index	1.06	1.06
Exposure index	0.99	0.99
Adaptive capacity index	1.45	1.45
Vulnerability index	0.6	0.6

From the scatter plots, 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 (Figure 4a). On the other hand, a lower sensitivity index will be associated with a lower exposure index, as is the case with maize yields in the south of Uganda. 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. Furthermore, the higher the exposure, the higher the level of vulnerability and vice versa. The coefficient of determination of 0.92 means that about 92% of the changes in vulnerability can be explained by the exposure (Figure 4b). As seen on Figure 5a–c, towards higher latitudes in Uganda (north), the exposure, sensitivity and vulnerability of maize yields to droughts increases and vice versa.

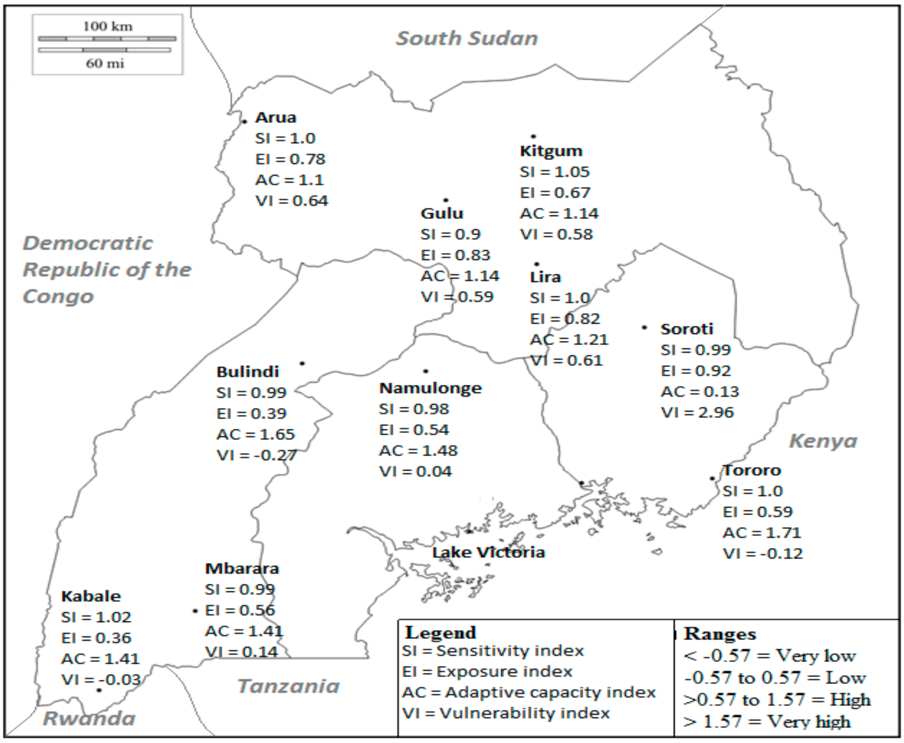

Figure 3. The spatial pattern of crop yield sensitivity, exposure, adaptive capacity and vulnerability indices for various districts/sites in Uganda.

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 (Figure 3). In general, all of the sites in the south have higher adaptive capacity indices than those in the north. The implication here is that maize production farmers in the south have a higher adaptive capacity to droughts than those in the north, based on the indicators used. When the adaptive capacity is high in the south, vulnerability is low. The scatter plots of adaptive capacity to droughts against vulnerability illustrates that, when adaptive capacity is high as in the south of Uganda, vulnerability is low (Figure 4c). On the other hand, when adaptive capacity is lower, as is observed in the north of Uganda, vulnerability is high. 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 the same 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 (Figure 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 the south of the country, which are cumulatively higher, with the highest adaptive capacity index in the south being 1.71 recorded in Tororo.

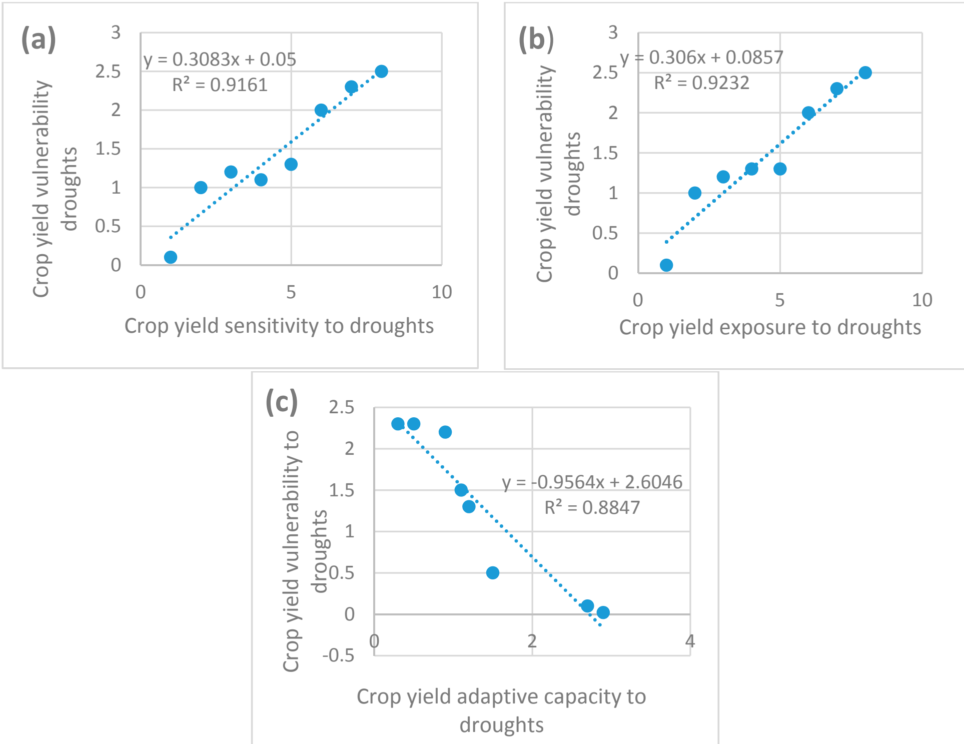

Figure 4. Relationship between crop yield vulnerability to droughts and (**a**) crop yield sensitivity to droughts, (**b**) crop yield exposure to droughts and (**c**) crop yields' adaptive capacity to droughts.

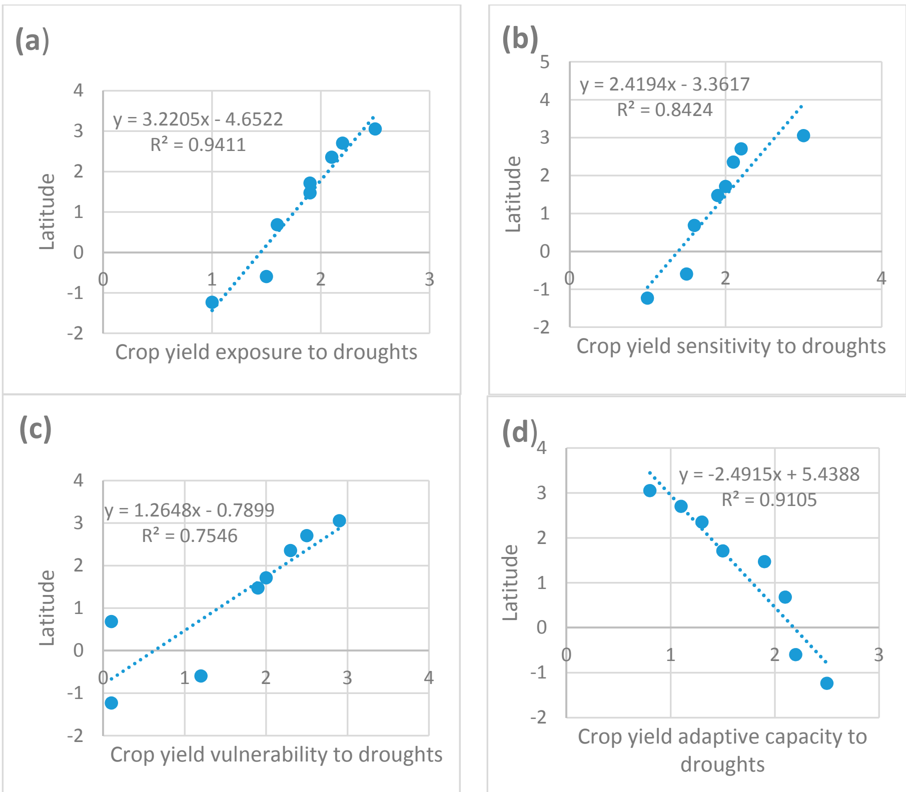

Figure 5. Relationship between latitude and (**a**) crop yield exposure to droughts, (**b**) crop yield sensitivity to droughts, (**c**) crop yield vulnerability to droughts and (**d**) crop yield adaptive capacity to droughts.

Adaptive capacity is the most important of all of 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 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. Simelton et al. [14] 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 a great deal if adaptations are adequate.

4. 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 [67,77–82]. There is an inverse relationship between latitude and precipitation in the Sahel [77,79–81]. The tendency for temperatures to increase with the increase in latitude and for precipitation to decrease with the increase in latitude is also consistent with a study conducted in Canada on the influence of droughts on tree mortality across Canada. The results show that between 1960 and 2000, higher temperatures and lower precipitation levels recorded above latitude 54° north while lower temperatures and higher precipitation levels recorded towards lower latitudes were responsible for the increased tree mortality (51°–54° and <51° north) [80]. In Uganda, 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) [41,42,65]. 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 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 [41]. 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 these observations. Daniels [76] 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 [72]. The UBOS [77] 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%. 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 and 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], which argues 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 with those from other studies [37,43,83–86]. Vulnerability to droughts in South Africa is linked to the degree of socio-economic development; assets, whether financial, human, natural, physical and social aspects do greatly affect the ability of a community to cope with climate change-related problems [37,43,83–86]. Socially, Pretty [87] 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 [88]. 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 [76]. 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 [32,56,68,69]. The level of education (human asset) does affect the ability to understand climate change-related information [89].

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 southwest 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 [19,90]. 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 and sandy with low productivity [19,60,90]. With threats of desertification and low average annual precipitation, the problems of food security are only likely to be accentuated in the north of Uganda. Besides, the situation may even deteriorate as model-based projections of surface temperature changes over east Africa may approach 6 °C by 2100 in an extreme scenario, while more conservative changes show increases just around the 2 °C mark [91,92]. In the case of precipitation, projections show changes in the range of +20% or −20% by the year 2100. In spite of this distribution, it is worth mentioning that the south 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. On the other hand, much of the spatial and temporal variations in the response of different crops to climate change across east Africa have been attributed to changes in temperature and to a lesser extent changes in water resource distribution [82,93,94]. Even though precipitation is reported to have begun recovering from the 1990s [39], in most of Africa, droughts still remain recurrent due to problems of timing and distribution of the precipitation increase [37,40].

5. Conclusions

The results show 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 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 the 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, such as floods, winds and even volcanic eruptions or natural hazards in general. The adaptive capacity sub-component of the index provides a statistical basis 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.

While this study made use of precipitation data, spanning the period 1960–2012 for the site-level assessments, the study is limited by the fact that the crop yield data for the site level assessments only covered the period 1999–2011; the only period for which data were available for a typical site-scale study. For the national-scale analysis, this study uses precipitation data for the period 1941–2014. Furthermore, our adaptive capacity index is weakened as it reflects only two proxies: poverty and literacy rates; in reality, the index will perform better if it reflects the myriad of proxies that affect adaptive capacity. The suggested vulnerability index is context specific and useful under the specific context presented by Uganda. However, the index can always be adapted to different internal realities of different regions. The variations in vulnerability and adaptive capacity at the district level show that specific climate change adaptation options have to be used. The fact that maize yields in the north of Uganda are more vulnerable to droughts reveals that all stakeholders must seek ways of making maize production more resilient to recurrent droughts through agroforestry, irrigation, agroecology-based organic nutrient inputs, research, training and innovation and information diffusion.

This vulnerability index can definitely be used to examine 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 basis 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. In addition to testing the applicability of these indices in other developing countries, the current requirements with respect to further research in the area of adaptation indices should emphasize the creation of a conceptual framework, as well as a 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. Such an index could also provide a platform from which different stakeholders (civil society, private sector and public sector) could evaluate their level of involvement and success in climate change adaptation. Designing scenarios and testing the effects of future temperature changes could be a good way of evaluating and forecasting future vulnerability.

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