



Mapping Meteorological Drought-vulnerability Extent for Isingiro District (1982-2022)

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10.18805/ag.DF-596

ABSTRACT

Background: Climate change and associated prolonged meteorological drought have affected crop productivity and food security for decades across the world. Most developing countries including Uganda are majorly affected due to their limited social, economic and technical capacity in climate change mitigation. Isingiro district for instance, is located in the Ugandan dry cattle corridor and has been affected by prolonged meteorological drought resulting in limited crop productivity and food insecurity for the last four decades. The extent to which meteorological drought has affected Isingiro district is not well documented hence the need for this study. The study aimed at mapping meteorological drought-vulnerable extent for the selected six sub-counties of Isingiro District, South Western Uganda. **Methods:** Precipitation datasets from 1982-2022 were downloaded from NASA powers website. SPI calculator, QGIS 3.4 and ArcGIS10 software were used to calculate SPI values and map the extent of meteorological drought in the selected sub counties. **Result:** Results show increasing average annual negative and extreme meteorological vulnerability following the order: Masha - 2.57 > Mbaare -2.40 > Kikagate -2.28 > Isingiro Town Council -2.26 = Rushasha -2.26 > Kashumba -2.05 indicating extremely high vulnerability of the study sub counties to meteorological drought. Results are discussed, conclusions and recommendations are provided in the manuscript.

Key words: Climate Change vulnerability, Climate-smart water conservation, Drought tolerant crops, Maize, Meteorological drought, Standard precipitation index.

INTRODUCTION

Climate change and variability affect food and income security across the globe. This includes, *inter alia*, meteorological drought, changes in weather patterns and unpredictable rainfall. Uganda and especially Isingiro district has been negatively affected by meteorological drought for the last four decades. Being located in the dry cattle corridor of Uganda, Isingiro district has suffered from meteorological drought for decades (Epule *et al.*, 2017). Meteorological drought is a type of drought that occurs when an area experiences a prolonged period of abnormally low rainfall, usually compared to the average rainfall amount in that region (Blauhut, 2020). This type of drought is focused solely on the meteorological aspects of drought, such as precipitation and temperature (Mondol *et al.*, 2017). Some key aspects of meteorological drought include:

1. Reduced precipitation

Meteorological drought is characterized by a significant decrease in precipitation over an extended period, often several months or even years.

2. Duration

The duration of meteorological drought can vary greatly, ranging from a few months to several years or even decades.

3. Severity

The severity of meteorological drought can also vary, depending on the amount of precipitation deficit and the impact on the surrounding environment.

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How to cite this article: Tumwesigye, W., Bedadi, B., Osiru, D., Tefera, T.L., Jackson-Gilbert, M.M. and Bamwesigye, D. (2024). Mapping Meteorological Drought-vulnerability Extent for Isingiro District (1982-2022). Agricultural Science Digest. doi: 10.18805/ag.DF-596.

Submitted: 08-01-2024 **Accepted:** 30-08-2024 **Online:** 04-10-2024

4. Impact on water resources

Meteorological drought can lead to reduced water availability, affecting surface and groundwater sources and impacting agriculture, industry and human consumption.

5. Regional variability

Meteorological drought can occur in any region and its impacts can vary greatly depending on the local climate, geography and water management practices. Some common indices used to measure meteorological drought include:

i. Standardized precipitation index (SPI) and ii. Palmer Drought Severity Index (PDSI). This study used SPI and selected sub counties from Isingiro district.

The standardized precipitation index (SPI) is a widely used tool for characterizing meteorological drought on various timescales and is among the most commonly used across the globe (Prathima *et al.*, 2023). It's a statistical index that essentially describes how unusual a particular precipitation amount is for a specific location and time of year. The SPI transforms precipitation data into a standardized scale, allowing for easy comparison of drought conditions across different regions and climates.

Data collection

Precipitation data for a specific location and time period are collected.

Probability distribution

The precipitation data are fitted to a probability distribution, typically the gamma distribution.

Calculation of SPI

The SPI is calculated based on the probability of precipitation for a given time period. It's essentially the number of standard deviations by which the observed precipitation value deviates from the long-term mean precipitation value. A positive SPI value indicates wetter than average conditions. A negative SPI value indicates drier than average conditions. The magnitude of the SPI value indicates the severity of the deviation from the long-term average, with more negative or positive values indicating more extreme conditions.

Timescale

SPI can be calculated for various timescales, such as 1 month, 3 months, 6 months, 12 months, *etc.*, depending on the specific application.

Scarcity of and too much rainfall affects crop productivity and food security in many parts of the Isingiro District. Previous researchers pointed out that prolonged meteorological drought has been the major threat to food and income insecurity among smallholder farmers in Isingiro District (Twongyirwe *et al.*, 2019). Meteorological drought affects soil fertility, the social, economic and food security of smallholder farmers in most developing counties (Kachiguma *et al.*, 2023). It negatively affects the hydrology, soil water, relative humidity, temperature, soil structure and species diversity (Benton and Newell, 2014; Lu *et al.*, 2017; Segurado *et al.*, 2016; Woods *et al.*, 2008). Furthermore, meteorological prolonged drought affects agricultural activities such as crop productivity, livestock,

fisheries and apiary hence peoples' livelihoods in various countries across the globe (Azadi *et al.*, 2018) and affects farmers livelihoods (Kakeeto *et al.*, 2019). This is exacerbated by smallholder farmers' high poverty levels and technical inability to mitigate the impacts of prolonged meteorological drought in their regions.

Previous studies linked land degradation, drought and desertification with poor socioeconomic development and human welfare (Mariano *et al.*, 2018). Landscapes affected by drought are, in most cases, degraded and are not suitable for supporting agricultural activities and healthy livelihoods (Webb *et al.*, 2017). Mapping meteorological drought vulnerability landscapes is pertinent for policy review and formulation thus supporting Uganda's sustainable developmental objectives. Previous researchers also linked drought with climate change, water resources management and food security in Isingiro District (Nagasha *et al.*, 2019; Twongyirwe *et al.*, 2019; Zziwa *et al.*, 2015) but their studies did not focus on meteorological drought that undermines crop production. Moreover, Ugandan agricultural challenges are more policy-related and climate is one other policy issue that needs timely intervention (Lu *et al.*, 2017; Rwamigisa, 2019).

The extent to which meteorological drought has affected the six sub-counties (Masha, Mbare, Kikagate, Isingiro Town Council, Rushasha and Kashumba) of Isingiro district is not well documented hence the need for this study. The study aimed at mapping the extent of meteorological drought vulnerability for the study sub counties of Isingiro District in the last 4 decades (1982 to 2022).

MATERIALS AND METHODS

The study used a qualitative study design involving key informant interviews using interview guides (Creswell, 2009) and secondary datasets. Key Informant interviews were conducted using 2 Senior District Officers, 2 natural resource officers and 4 Sub-County agronomists to identify the most maize-growing sub-counties which are also drought-vulnerable in the district. The participants identified six sub-counties (Table 1). To validate their submissions, climate data were obtained from NASA POWERS website (<https://power.larc.nasa.gov/data/>) accessed on 10th April 2024 at a spatial resolution of 0.05° (5.5 km × 5.5 km) using the geographic coordinates for each sub-county. Data was analyzed using SPI calculator based on the daily

Table 1: Geographic coordinates of study sub-counties of Isingiro District.

SC	Latitude	Longitude
Town council	-0.134712	30.49500
Masha	-0.66873,	30.76987
Rushasha	-0.73373	31.0036
Kikagate	-1.04251	30.66324
Kashumba	-0.89508	30.93366
Mbare	-0.95000	31.03333

rainfall received in each sub-county for the last 40 years (1982-2022). Secondary data for 2022 maize yields was obtained from the district production office (Table 2). The SPI variations for four decades were tabulated and associated bar charts were drawn using Microsoft Excel 2021 thus establishing the extent of vulnerability to meteorological drought for each study sub-counties. This was supplemented by the application of ArcGIS 10, QGIS 3.4 and SPI calculator software for further data analysis.

Description for study area

The study was conducted in Isingiro District in the southwestern part of Uganda located between coordinates 0.84°S (-0.134712°) and 30.80°E (30.49500°) (Fig 1). The region is found in the dry cattle corridor for Uganda at an elevation of 1455.72 meters (4775.98 feet) above sea level, Isingiro has a Tropical wet and dry or savanna climate (Classification: Aw). The district's yearly temperature is 22.01°C (71.62°F) and it is -1.46% lower than Uganda's averages. Isingiro typically receives about 357.72

millimeters (14.08 inches) of precipitation and has 282.18 rainy days (77.31% of the time) annually (GoU, 2014).

Table 1 show the geographic coordinates for the study sub counties of Isingiro district, south western Uganda. All the six sub counties are located below the equator and slightly more than 30° west of the Prime Meridian (Greenwich).

Table 2 shows classification for meteorological drought based on SPI values. Standard Precipitation Index (SPI) for the selected sub-counties were calculated using SPI calculator for 40 years 1982-2022 based on standard procedures recommended by previous experts based on drought assessment protocols. (W.M.O., 1987).

RESULTS AND DISCUSSION

Table 3 shows average annual SPI values for the last 40 years (1982-2022). All the six study sub counties show minimum high negative average annual SPI values less or equal to -2 demonstrating extreme dryness through the entire region.

Table 4 show annual maize yields for the six sub counties studies for the years 2022. All the sub counties show 3 tons/ha which is less than the average maize yields for the entire country between 4-9 tons/ha depending on the variety and environmental characteristics (Wakabi, 2016).

Table 5 shows annual average SPI values for six study sub counties of Isingiro district. Severity of meteorological drought increases in order: Masha -2.57 > Mbaare -2.40 > Kikagate -2.28 > Isingiro Town Council -2.26 = Rushasha -2.26 > Kashumba -2.05.

Table 2: Drought classification based on SPI.

SPI values	Classification
2.0 or more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 or less	Extremely dry

(Source: Tigkas *et al.*, 2015).

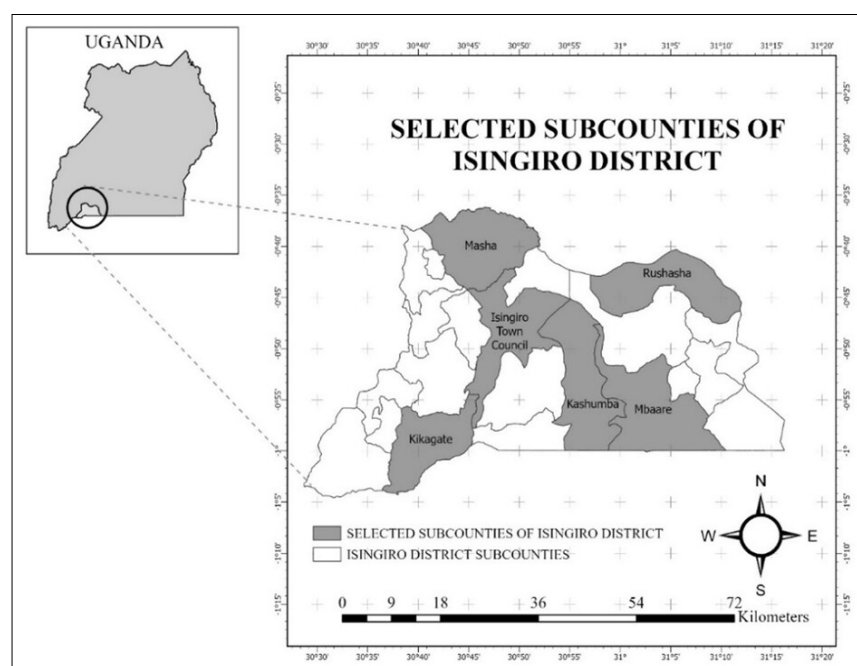


Fig 1: Map of Africa showing the location of the study sub counties.

Table 3: Time series variations of SPI with time for study sub counties 1982-2022.

Year	Isingiro town council SPI				Rushasha sub county SPI				Kashumba sub county SPI				Kikagata sub county SPI				Masha sub county SPI				Mbaare sub county SPI			
	6	12	24		6	12	24		6	12	24		6	12	24		6	12	24		6	12	24	
1982	-0.19	0.84	-1.54		0.20	-0.84	-0.33		-0.19	-0.85	-1.00		-0.21	-0.67	-0.46		-0.19	-0.56	-0.46		-0.23	-0.84	-0.78	
1983	0.12	0.01	-0.99		1.01	0.69	-0.97		0.12	0.01	-0.52		0.12	0.01	-0.35		0.41	0.25	-0.35		1.01	0.69	-0.97	
1984	-1.09	-0.78	-0.45		-0.57	0.41	-0.45		-1.09	-0.78	-0.45		-1.09	-0.78	-0.45		-0.50	-0.07	-0.45		-0.57	0.41	0.11	
1985	-0.42	-0.59	-0.83		0.03	-0.35	-0.83		-0.42	-0.59	-0.83		-0.41	-0.60	-0.83		-0.40	-0.54	-0.83		0.03	-0.35	-0.34	
1986	-0.90	-0.92	-0.93		0.01	0.16	-0.93		-0.90	-0.92	-0.93		-0.92	-0.92	-0.95		-0.71	-0.45	-0.95		0.01	0.16	-0.60	
1987	0.60	0.69	-0.04		0.97	1.00	-0.04		0.60	0.69	-0.04		0.61	0.70	-0.03		0.64	0.50	-0.03		0.97	1.00	0.07	
1988	0.84	0.81	0.88		1.15	1.23	0.88		0.84	0.81	0.88		0.84	0.82	0.91		1.01	1.06	0.91		1.15	1.23	0.92	
1989	-0.19	0.15	0.58		0.30	0.76	0.58		-0.19	0.15	0.58		-0.20	0.16	0.60		0.26	0.52	0.60		0.30	0.76	0.93	
1990	0.53	0.33	0.28		-0.03	-0.20	0.28		0.53	0.33	0.28		0.52	0.33	0.30		0.59	0.47	0.30		-0.03	-0.20	0.58	
1991	-0.08	0.31	0.39		0.34	0.56	0.39		-0.08	0.31	0.39		-0.07	0.32	0.41		0.03	0.39	0.41		0.34	0.56	0.51	
1992	-1.57	-2.38	-0.87		-1.12	-1.12	-0.87		-1.57	-2.38	-0.87		-1.58	-2.39	-0.88		-1.48	-1.96	-0.88		-1.12	-1.12	-0.64	
1993	-1.53	-2.24	-2.83		-1.83	-3.00	-2.83		-1.53	-2.24	-2.83		-1.53	-2.25	-2.88		-1.38	-1.84	-2.88		-1.83	-3.00	-2.37	
1994	-1.12	-1.79	-2.43		-1.28	-1.83	-2.43		-1.12	-1.79	-2.43		-1.14	-1.81	-2.47		-0.78	-1.35	-2.47		-1.28	-1.83	-1.89	
1995	-0.05	-0.04	-0.96		0.62	0.55	-0.96		-0.05	-0.04	-0.96		-0.04	-0.04	-0.97		0.43	0.42	-0.97		0.62	0.55	-0.37	
1996	0.77	0.44	0.22		1.13	1.05	0.22		0.77	0.44	0.22		0.77	0.44	0.23		0.29	0.20	0.23		1.13	1.05	0.35	
1997	0.06	0.44	0.54		0.16	0.61	0.54		0.06	0.44	0.54		0.04	0.45	0.56		0.06	0.36	0.56		0.16	0.61	0.32	
1998	-0.38	-0.12	0.18		-0.55	-0.10	0.18		-0.38	-0.12	0.18		-0.40	-0.11	0.20		-0.55	-0.12	0.20		-0.55	-0.10	0.15	
1999	-1.18	-1.38	-0.85		-1.16	-1.16	-0.85		-1.18	-1.38	-0.85		-1.18	-1.38	-0.86		-1.47	-2.30	-0.86		-1.16	-1.16	-1.23	
2000	-0.66	-1.39	-1.64		-0.24	-1.02	-1.64		-0.66	-1.39	-1.64		-0.67	-1.40	-1.67		-0.57	-1.15	-1.67		-0.24	-1.02	-2.05	
2001	0.04	0.04	-0.71		-0.11	0.28	-0.71		0.04	0.04	-0.71		0.02	0.04	-0.71		-0.32	-0.17	-0.71		-0.11	0.28	-0.70	
2002	-0.38	-0.16	-0.10		-0.78	-0.88	-0.10		-0.38	-0.16	-0.10		-0.40	-0.16	-0.10		-0.38	-0.14	-0.10		-0.78	-0.88	-0.20	
2003	-0.33	-0.50	-0.43		-1.19	-1.07	-0.43		-0.33	-0.50	-0.43		-0.35	-0.50	-0.43		-1.05	-1.07	-0.43		-1.19	-1.07	-0.69	
2004	0.52	0.57	0.07		-0.11	-0.10	0.07		0.52	0.57	0.07		0.51	0.57	0.08		-0.09	-0.08	0.08		-0.11	-0.10	-0.64	
2005	0.63	0.76	0.78		0.00	-0.10	0.78		0.63	0.76	0.78		0.63	0.77	0.81		-0.69	-0.76	0.81		0.00	-0.10	-0.49	
2006	-0.80	-0.59	0.17		-0.66	-0.89	0.17		-0.80	-0.59	0.17		-0.80	-0.59	0.18		-0.86	-0.92	0.18		-0.66	-0.89	-1.02	
2007	0.30	0.18	-0.23		0.95	0.97	-0.23		0.30	0.18	-0.23		0.31	0.18	-0.23		0.13	-0.01	-0.23		0.95	0.97	-0.53	
2008	0.42	0.52	0.40		-0.02	0.20	0.40		0.42	0.52	0.40		0.44	0.53	0.42		-0.26	-0.08	0.42		-0.02	0.20	-0.07	
2009	0.18	0.25	0.44		-0.15	-0.25	0.44		0.18	0.25	0.44		0.18	0.26	0.46		0.38	0.25	0.46		-0.15	-0.25	0.10	
2010	0.17	0.46	0.41		0.25	0.20	0.41		0.17	0.46	0.41		0.17	0.47	0.43		0.17	0.29	0.43		0.25	0.20	0.30	
2011	0.12	-0.11	0.20		0.40	0.31	0.20		0.12	-0.11	0.20		0.11	-0.11	0.22		0.19	0.42	0.22		0.40	0.31	0.40	
2012	-0.03	0.20	0.03		0.12	0.47	0.03		-0.03	0.20	0.03		-0.04	0.21	0.04		0.33	0.19	0.04		0.12	0.47	0.35	
2013	-0.05	0.11	0.15		0.05	0.02	0.15		-0.05	0.11	0.15		-0.04	0.11	0.16		-0.06	0.28	0.16		0.05	0.02	0.27	
2014	0.57	0.42	0.29		0.16	0.09	0.29		0.57	0.42	0.29		0.56	0.43	0.31		-0.10	-0.08	0.31		0.16	0.09	0.11	
2015	0.23	0.49	0.53		0.02	0.22	0.53		0.23	0.49	0.53		0.23	0.50	0.55		0.27	0.12	0.55		0.02	0.22	0.01	

Table 3: Continue...

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2016	0.02	0.03	0.30	-0.61	-0.58	0.30	0.02	0.03	0.30	0.30	0.03	0.04	0.31	0.00	0.22	0.31	-0.61	-0.58	0.20
2017	0.33	0.28	0.15	0.03	-0.25	0.15	0.33	0.28	0.15	0.15	0.33	0.28	0.17	-0.08	-0.32	0.17	0.03	-0.25	-0.03
2018	0.49	0.78	0.62	-0.83	-0.53	0.62	0.49	0.78	0.62	0.62	0.52	0.79	0.65	1.56	1.60	0.65	-0.83	-0.53	0.93
2019	0.07	-0.25	0.37	0.19	-0.23	0.37	0.07	-0.25	0.37	0.37	0.03	-0.25	0.38	1.06	1.19	0.38	0.19	-0.23	1.65
2020	1.90	2.00	1.26	1.33	1.53	1.26	1.90	2.00	1.26	1.26	1.82	2.01	1.29	1.70	1.57	1.29	1.33	1.53	1.63
2021	1.51	1.82	2.30	0.88	1.00	2.30	1.51	1.82	2.30	2.30	1.28	1.39	2.10	1.40	1.85	2.10	0.88	1.00	2.03
2022	1.30	1.38	1.93	1.48	1.46	1.93	1.30	1.38	1.93	1.93	1.74	1.68	1.87	1.70	1.57	1.87	1.48	1.46	2.03
Min SPI	-1.57	-2.38	-2.83	-1.83	-3.00	-2.83	-1.57	-2.38	-2.83	-2.83	-1.58	-2.39	-2.88	-1.48	-2.30	-2.88	-1.83	-3.00	-2.37
AV. SPI		-2.26			-2.55			-2.26							-2.05			-2.40	

Fig 2 presents variations of SPI values for Isingiro Town Council from 1982-2022 divided in two parts: -1982-2002 (to the left); 2003-2022 (to the right). For the years 1998 to 2002, 1982 to 1986, 1998 to 2002, Isingiro Town Council experienced meteorological drought, as depicted by the negative SPI values -1 to -2.8. Wet years that are likely to have experienced some amount of rainfall include: 1987-1991, 1996-1997 and extremely wet years that might have received heavy rains include 2020-2022.

Fig 3 presents variations of SPI values for Rushasha Sub County from 1982-2022 divided in two parts: -1982-2002 (to the left); 2003-2022 (to the right). Negative SPI values were obtained for the years 1982-1986, 1990, 1992-1994, 1998-2002, 2003, 2006, 2016-2018 where the sub county experienced meteorological drought and wet years where the area might have obtained more rains include: 1983, 1987-1991, 1995-1997, 2007-2012. Heavy rains and extreme wet years include 2020-2022.

Fig 4 presents variations of SPI values for Kashumba Sub County from 1982-2022 divided in two parts: -1982-2002 (to the left); 2003-2022 (to the right). The sub county experienced meteorological drought during the years 1982-1986, 1992-1994, 199-2000 and 2006 where negative SPI values were obtained. On the other hand, rainfall and wet years with positive SPI include 1987-1991, 1996-1997, 2004-2005, 2007-2018. Heavy rains and extreme wet years include 2020-2022.

Fig 5 presents variations of SPI values for Kikagata Sub County from 1982-2022 divided in two parts: -1982-2002 (to the left); 2003-2022 (to the right). Negative SPI values were obtained during 1982-1986, 1992-1994, 1999-2002, 2003 and 2006 for Kikagata Sub County. Positive SPI values and most likely rainfall was obtained during the years: -1987-1991, 1986-1997, 2004-2005, 2007-2019. Heavy rains might have been received resulting in extreme wetness for the sub county during 2020-2022.

Fig 6 presents variations of SPI values for Masha Sub County from 1982-2022 divided in two parts: -1982-2002 (to the left); 2003-2022 (to the right). For Masha Sub County, meteorological drought was obtained during 1982-1986, 1992-1995, 1986-2006 where negative SPI values were obtained. Positive SPI values were obtained and most likely some rainfall during 183, 1987-1991, 1995-1997, 2008-2016 in the Sub County. Heavy rains and extreme wetness were obtained during 2020-2022.

Fig 7 presents variations of SPI values for Mbare Sub County from 1982-2022 divided in two parts: -1982-2002 (to the left); 2003-2022 (to the right). The sub county experienced meteorological drought with negative SPI values during 1982-1986, 1992-1994, 1999-2006, 2016-2019. Positive SPI values indicating wetness and some rains were obtained for the years 1983, 1987-1991, 1995-1997, 2007-2015. Heavy rains and extreme wetness were obtained during the years 2020-2022.

Table 6 presents annual rainfall and temperatures for the six study sub counties. Generally, the annual rainfall is

Table 4: Maize production for six study sub counties of Isingiro district in 2022.

Isingiro district local government				
Production levels per sub-county Jan 2022				
Maize				
Sub-county	Land area (KM ²)	Land area (Ha)	Total area under maize in Ha (Est)	Annual yield (Tons/Ha)
Endinzi	122.4	12240.0	23.4	3.0
Kashumba	178.0	17800.0	22.0	3.0
Ngarama	244.0	24400.0	35.1	3.0
Rugaaga	199.8	19980.0	34.1	3.0
Mbaare	168.0	16800.0	102.7	3.0
Birere	152.8	15280.0	23.6	3.0
Kabingo	156.2	15620.0	90.0	3.0
Kabuyanda	137.0	13700.0	356.9	3.0
Kikagate	416.0	41600.0	522.7	3.0
Masha	189.4	18940.0	112.7	3.0
Nyakitunda	301.0	30100.0	175.0	3.0
Isingiro TC	189.4	18940.0	133.7	3.0
Kaberebere TC	61.5	6150.0	7.9	3.0
Kabuyanda TC	93.0	9300.0	142.8	3.0
Rushasha	111.4	11140.0	130.9	3.0
Ruborogota	171.7	17170.0	73.9	3.0
Nyamuyanja	119.0	11900.0	33.9	3.0
Total	3,010.60	260,850.00	2,021.14	51.0

Table 5: Average annual negative SPI for study sub counties 1982-2022.

40-Year average negative annual SPI 1982-2022	
Sub county	SPI
Isingiro town council	-2.26
Masha	-2.57
Rushasha	-2.26
Kikagate	-2.28
Kashumba	-2.05
Mbaare	-2.40

Table 6: Annual rainfall and temperature variations for study sub counties.

Annual rainfall (mm) and temperature (°C) for study sub counties 2020			
Sub county	Rainfall	Tmin	Tmax
Isingiro TC	5.27	11.19	30.64
Masha	5.27	11.02	27.92
Rushasha	5.27	12.05	28.86
Kikagate	5.27	11.19	29.48
Kashumba	5.27	11.19	29.48
Mbaare	5.27	11.8	29.48

low and annual temperatures are high for all the sub counties thus making them most likely to be less suitable for optimum maize productivity.

Fig 8 shows the SPI and rainfall variability for six sub-counties where the study was conducted. Over the last four

decades, Kikagate, Isingiro Town Council, Masha and Ngarama obtained negative SPI values between -1.5 to -1.49 indicating vulnerability to meteorological drought of the region. The same sub counties experienced annual rainfall between 1011 mm-1091 mm. To understand better rainfall variability and Sub Counties vulnerable to meteorological drought in Isingiro District, ArcGIS10 software was used and standard procedures were followed based on previous experts to produce a standard map (Mondol *et al.*, 2017).

To get more understanding of the region, further analysis using QGIS 3.4 revealed that the study sub counties were vulnerable to drought (2001-2015) which has a negative implication on maize productivity in the region.

Fig 9 shows drought vulnerability 2001-2015 for the study sub counties in Isingiro district. More than half the land cover for Mbaare, Kashumba, Ngarama, Kikagate and Isingiro Town Council is vulnerable to prolonged drought and the landscape is degraded to a large extent.

Mapping and monitoring

SPI values can be mapped to show areas experiencing drought or surplus conditions, helping policy makers, water managers and other stakeholders to monitor drought conditions and make informed decisions regarding water resource management, agriculture and disaster preparedness. Overall, the SPI is a valuable tool for drought monitoring, as it provides a standardized measure that can be easily interpreted and compared across different regions and time periods.

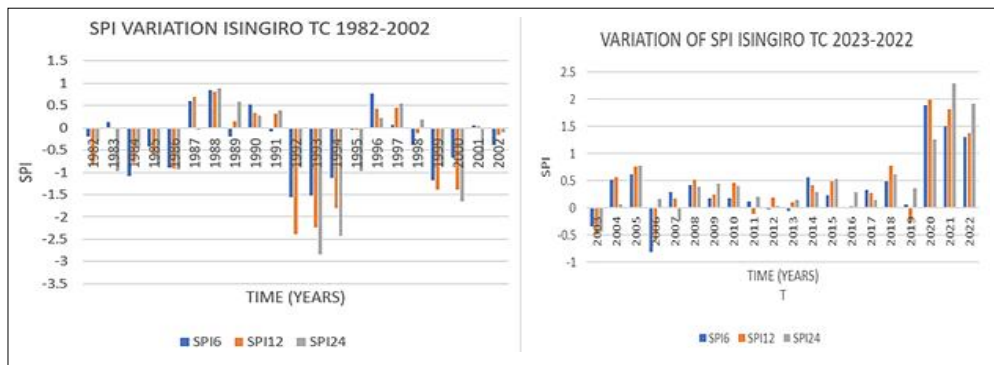


Fig 2: Variation of SPI for Isingiro TC 1982-2002;2002-2022.

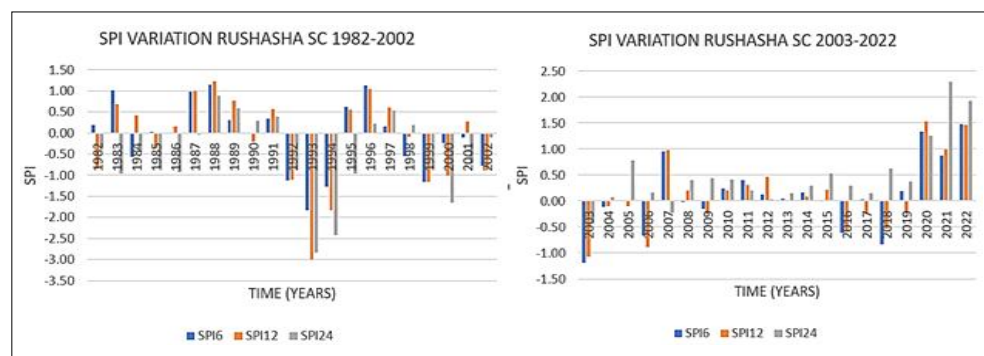


Fig 3: Variation of SPI with time for Rushasha Sub country 1982-2002; 2003-2022.

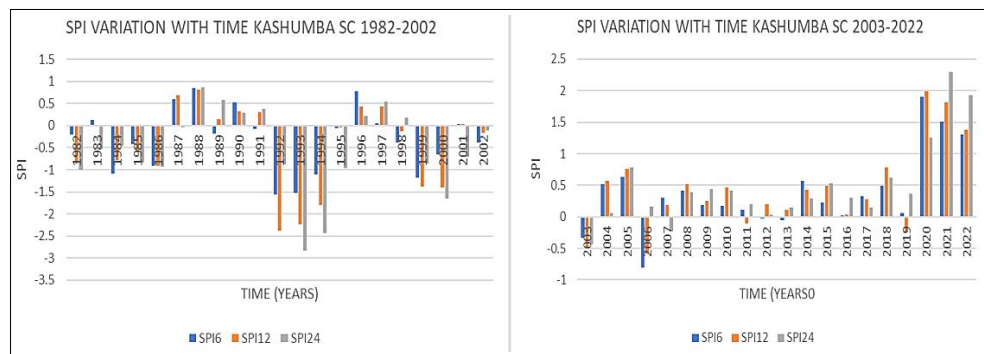


Fig 4: Variation of SPI with time for Kashumba Sub country 1982-2002;2003-2022.

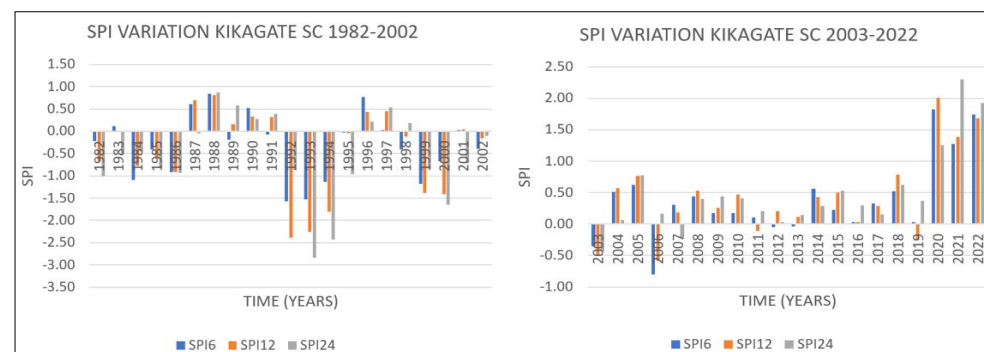


Fig 5: SPI variation with time for Kikagate sub county 1982-2022.

Results agree with previous findings that Standardized Precipitation Index (SPI) can have a significant effect on maize productivity, as maize is highly sensitive to water availability throughout its growth cycle. SPI can impact maize productivity as follows:

Drought stress

Negative SPI values indicate drier than average conditions, which can lead to drought stress for maize plants. Insufficient

moisture during critical growth stages such as germination, flowering and grain filling can result in reduced plant growth, lower kernel development and ultimately decreased yields.

Water stress during critical growth stages

Maize requires adequate water during critical growth stages to optimize yield potential. If SPI indicates prolonged periods of below-average precipitation during these stages, it can lead to water stress and reduced productivity (Fisher *et al.*, 2015).

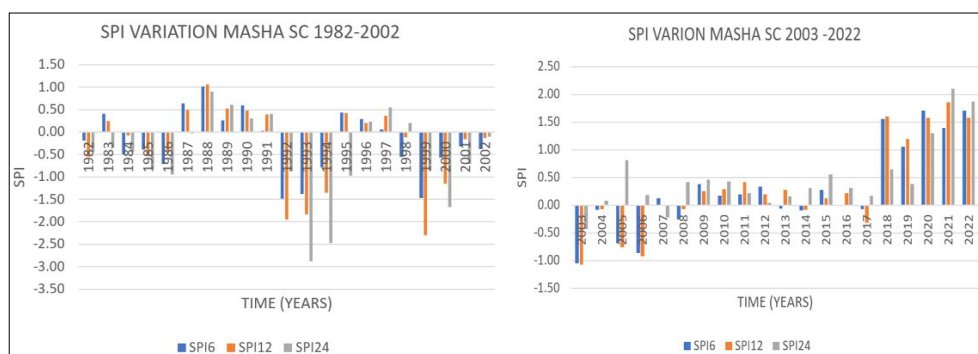


Fig 6: SPI Variation with time for Masha sub county 1982-2022.

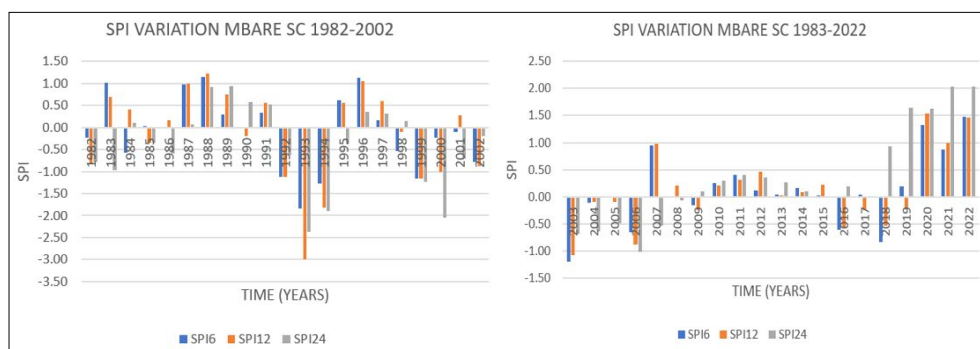


Fig 7: Forty-year SPI variations with time for Mbare sub county 1982-2022.

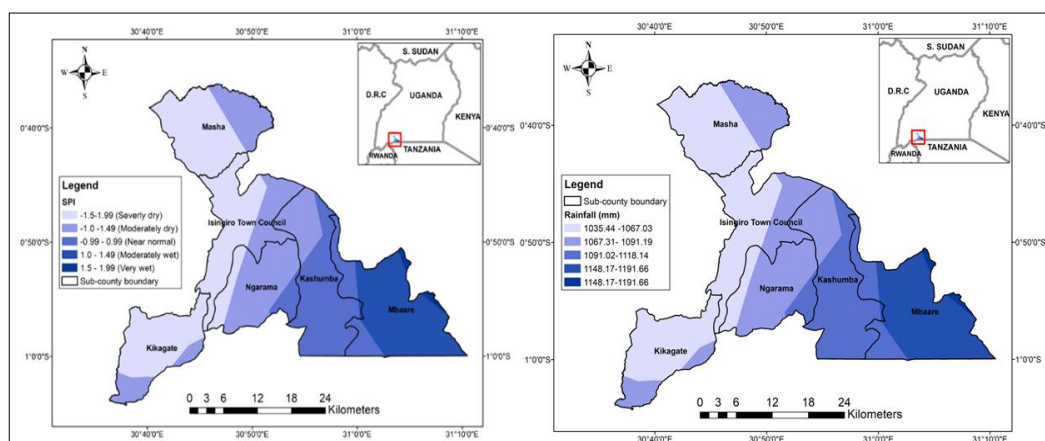


Fig 8: Time series analysis of SPI and rainfall variability for the study sub-counties (1982-2022).

This study is in agreement with this study previous researchers reported that in regions where SPI indicates delayed onset of the rainy season or prolonged dry spells, maize planting may be delayed. Delayed planting can lead to shorter growing seasons, reduced time for crop development and lower yields. Additionally, reduced moisture availability during germination can lead to poor seedling establishment and lower overall plant populations (Fisher *et al.*, 2015).

Impact on soil moisture availability

SPI reflects not only current precipitation but also precipitation over longer timescales. Prolonged negative SPI values can lead to depletion of soil moisture, further exacerbating water stress for maize plants, especially in rain fed agricultural systems (Steward *et al.*, 2018a).

Additionally, this study agrees with previous researchers who stated that farmers and agricultural planners often use SPI data to inform decision-making regarding crop selection, planting dates, irrigation scheduling and other management practices. In regions where SPI indicates potential drought conditions, farmers may implement drought-tolerant maize varieties, adopt conservation tillage practices to conserve soil moisture, or invest in irrigation infrastructure to supplement water availability (Tesfaye *et al.*, 2018).

The study agrees with previous studies which pointed out that SPI variability can lead to yield variability from one growing season to another. This variability can have significant economic implications for maize farmers, affecting their income and livelihoods. In regions heavily reliant on maize production for food security and economic stability, fluctuations in maize productivity due to SPI variations can have far-reaching consequences (Msowoya and Madani, 2016). Overall, the SPI serves as a valuable

tool for assessing the potential impact of precipitation variability on maize productivity, helping farmers and policymakers develop strategies to mitigate the adverse effects of drought and optimize yields in maize-growing regions (Okal *et al.*, 2020).

This research agrees with previous studies which reported that Standardized Precipitation Index (SPI) on maize productivity has been widely studied, as maize is one of the most important cereal crops globally. Drought Stress and Yield Reduction: Negative SPI values, indicating drought conditions, have been consistently linked to reduced maize yields. Studies have shown that drought stress during critical growth stages such as flowering and grain filling can significantly decrease maize productivity (Tao *et al.*, 2018; Yosef *et al.*, 2021). On the contrary, Positive SPI values, indicating surplus precipitation, can also influence maize productivity. However, excessive moisture can lead to waterlogging and nutrient leaching thus negatively impacting maize growth and yield (Jain *et al.*, 2019).

Temporal variability

SPI can exhibit temporal variability, with different timescales (e.g., monthly, seasonal) influencing maize productivity differently. For instance, prolonged dry spells during specific growth stages may have a more pronounced effect on yield compared to overall seasonal precipitation deficits (Gbegbelegbe *et al.*, 2017).

At the same time, the impact of SPI on maize productivity varies across different regions due to differences in climate, soil characteristics and farming practices. Studies have highlighted the importance of local-scale assessments to understand the specific effects of SPI on maize yields in different agro ecological zones (Zhang *et al.*, 2020).

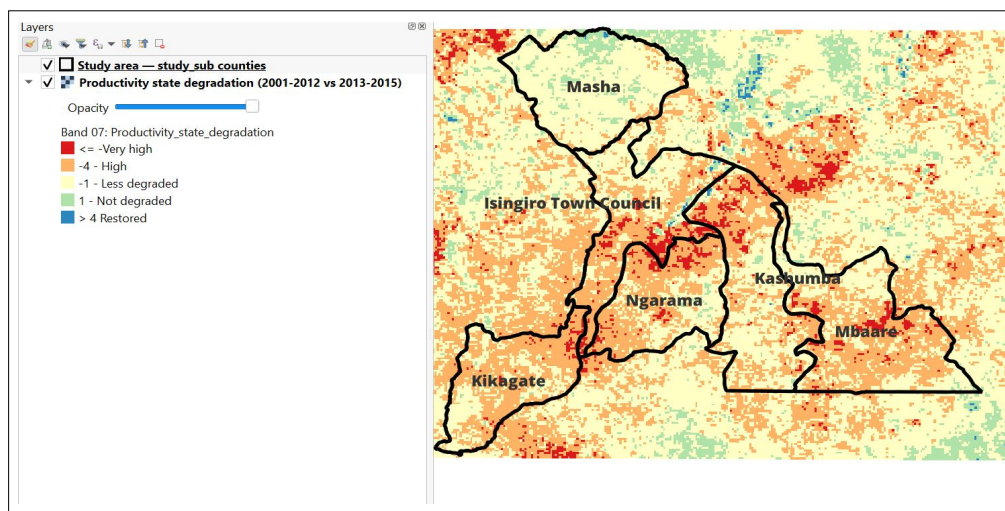


Fig 9: Drought vulnerable sub counties of Isingiro district.

Adaptation strategies

Farmers often employ various adaptation strategies to mitigate the adverse effects of SPI on maize productivity. These may include crop diversification, adoption of drought-tolerant maize varieties, improved water management practices and investment in irrigation infrastructure (Funk *et al.*, 2019; Alhassan *et al.*, 2020). Modeling Approaches: Statistical and modeling approaches integrating SPI data with crop growth models have been used to assess the relationship between precipitation variability and maize productivity. These studies provide valuable insights into the potential impacts of future climate scenarios on maize yields (Ruane *et al.*, 2018).

The findings of this study are in agreement with previous studies which reported that prolonged drought degrades landscape hence threatening food security of different regions (Araya *et al.*, 2015; Katengeza *et al.*, 2019; Steward *et al.*, 2018b). Additionally, the majority of the population in Isingiro depend on agriculture for their livelihoods and meteorological drought negatively affects their crop production hence their livelihoods (Twongyirwe *et al.*, 2019). Extreme drought and land degradation result in households increased famine and prolonged shortage of food causing widespread diseases and deaths from starvation (Mulinde *et al.*, 2019; Surendra *et al.*, 2012). The findings also agree with the District Multi-hazard assessment report conducted by the Prime minister's office which concluded that "the most affected sub-counties by drought were Kikagate and Masha, Rugaaga, Kashumba, Isingiro TC and Ngarama in that order of severity" (NECOC, 2017). Additionally, household food shortage has enhanced land conflicts between locals and refugees, resulting into migration of people from Isingiro to Tanzania to look for food and livestock feeds for their households (NECOC, 2017) thus exacerbating conflicts between the two countries.

Moreover, this study agrees with previous researchers who pointed out that prolonged drought has been the major threat to food and income insecurity among smallholder farmers in Isingiro District (Twongyirwe *et al.*, 2019). Previous scholars classified drought into three categories namely. Meteorological drought; Agricultural drought and Hydrological drought (Shobanadevi *et al.*, 2022). The first category is the precursor for the rest and all of them negatively affect crop production and smallholder farmers' livelihoods. Prolonged drought affects the social, economic and food security of smallholder farmers in most developing countries. It negatively affects the hydrology, soil water, relative humidity, temperature, soil structure and species diversity (Benton and Newell, 2014; Lu *et al.*, 2017; Segurado *et al.*, 2016; Woods *et al.*, 2008).

Furthermore, prolonged drought affects agricultural activities such as crop productivity, livestock, fisheries and apiculture hence peoples' livelihoods in various countries (Azadi *et al.*, 2018). This is exacerbated by smallholder farmers' high poverty levels and technical inability to

mitigate the impacts of prolonged drought in their regions. This study also agrees with previous studies which linked land degradation, drought and desertification with poor socioeconomic development and human welfare (Mariano *et al.*, 2018). Most of the landscapes affected by drought have also been reported to be degraded hence not suitable for supporting crop production and peoples' livelihoods (Webb *et al.*, 2017). Mapping meteorological drought vulnerability and landscape degradation are pertinent for policy review and formulation thus supporting Uganda's sustainable developmental objectives and motivation for small holder farmers to look for drought-resilient varieties to increase crop productivity (Shobanadevi *et al.*, 2022). Similarly, previous researchers linked drought with climate change, water resources management and food security in Isingiro District (Nagasha *et al.*, 2019; Twongyirwe *et al.*, 2019; Zziwa *et al.*, 2015).

CONCLUSION AND RECOMMENDATIONS

Over the four study decades, Isingiro District has suffered from meteorological drought and land degradation. All the six sub counties have negative annual mean SPI values indicating extreme meteorological drought, scanty, unreliable and limited rainfall. For the years 1992-1994 all the six sub counties show large negative SPI values indicating extreme meteorological drought that might have affected maize productivity across the study area.

On the other hand, for the years 2020-2022, all the study sub counties demonstrate high positive SPI values indicating very wet conditions and mostly much rainfall in the study area. This can likely be attributed to climate change mitigation intervention options including climate change awareness creation, tree planting, alternative energy initiative supported by the Development Response to Displacement Impacts Project (DRDIP) in the region.

Most of the smallholder farmers depend on rain-fed agriculture and meteorological drought degrades landscape and negatively affects farmers' livelihoods. Drought has enhanced landscape degradation and reduced maize productivity in the region. The scarcity of rain has affected smallholder farmers' crop productivity, income and household food security. The sub counties vulnerable to meteorological drought are at the same time most degraded and less productive in terms of crop and livestock sectors.

The study recommends climate-smart agricultural innovative practices that have the potential to improve soil-water conservation, boost crop productivity and mitigate climate change effects. These innovations include afforestation, agroforestry, reforestation, use of alternative energy sources, planting early maturing, disease resistant and high yield maize varieties for improving households' food and income security in the study area. Early-warning and weather insurance approaches are also recommended for the study sub counties.

ACKNOWLEDGEMENT

We thank the African Centre of Excellence for Climate Smart Agriculture and Biodiversity Conservation Management for the funding support they provided through the World Bank.

Conflict of interest

The authors declare that there is no competing interest.

REFERENCES

- Ahassan, R.M., Sulemana, M. and Zangina, D.T. (2020). Farmers' perception of climate variability and adaptation strategies in the Guinea Savannah Zone of Ghana. *Agricultural Systems*. 180: 102754.
- Araya, A., Hoogenboom, G., Luedeling, E., Hadgu, K.M., Kisekka, I. and Martorano, L.G. (2015). Assessment of maize growth and yield using crop models under present and future climate in southwestern Ethiopia. *Agricultural and Forest Meteorology*. 214: 252-265. <https://doi.org/10.1016/j.agrformet.2015.08.259>.
- Azadi, H., Keramati, P., Taheri, F., Rafiaani, P., Teklemariam, D., Gebrehiwot, K., Hosseininia, G., Van Passel, S., Lebailly, P. and Witlox, F. (2018). Agricultural land conversion: Reviewing drought impacts and coping strategies. *International Journal of Disaster Risk Reduction*. 31: 184-195. <https://doi.org/10.1016/j.ijdrr.2018.05.003>.
- Benton, M.J. and Newell, A.J. (2014). Impacts of global warming on permo-triassic terrestrial ecosystems. *Gondwana Research*. 25(4): 1308-1337. <https://doi.org/10.1016/j.gr.2012.12.010>
- Blauhut, V. (2020). The triple complexity of drought risk analysis and its visualisation via mapping: A review across scales and sectors. *Earth-Science Reviews*. 210: 103345. <https://doi.org/10.1016/j.earscirev.2020.103345>.
- Creswell, J. (2009). *The Selection of a Research Design*. In: *Research Design: Qualitative, Quantitative and Mixed Methods Approaches* (3rd ed.). Sage Publications, Inc.
- Epule, T.E., Ford, J.D., Lwasa, S. and Lepage, L. (2017). Vulnerability of maize yields to droughts in Uganda. *Water*. 1-17. <https://doi.org/10.3390/w9030181>.
- Fisher, M., Abate, T., Lunduka, R.W., Asnake, W., Alemayehu, Y. and Madulu, R.B. (2015). Drought tolerant maize for farmer adaptation to drought in sub-saharan Africa: Determinants of adoption in eastern and southern Africa. *Climatic Change*. 133(2): 283-299. <https://doi.org/10.1007/s10584-015-1459-2>.
- GoU. (2014). *National State of the Environment Report for Uganda 2014*.
- Jeyaseelan, A.T. (2003). Droughts and floods assessment and monitoring using remote sensing and GIS. *Satellite Remote Sensing and GIS Applications in Agricultural Meteorology*. pp 291-313.
- Kachiguma, N.A., Ifie, B.E., Maliro, M.F.A., Tongoona, P.B. and Ofori, K. (2023). Farmers' perceptions on drought, low soil fertility, coping strategies and preferred traits of beans (*Phaseolus vulgaris* L.) in Balaka District of Malawi. *Agricultural Science Digest*. 43(6): 889-893. <https://doi.org/10.18805/ag.DF-426>.
- Makeeto, R., Sibiya, J., Melis, R. and Biruma, M. (2019). Farmers' perceptions of drought and other production constraints, drought mitigation options and their implications for groundnut breeding in Uganda. *Indian Journal of Agricultural Research*. 53(1): 45-50. <https://doi.org/10.18805/IJARE.A-337>.
- Katengeza, S.P., Holden, S.T. and Fisher, M. (2019). Use of integrated soil fertility management technologies in Malawi: Impact of dry spells exposure. *Ecological Economics*. 156: 134-152. <https://doi.org/10.1016/j.ecolecon.2018.09.018>.
- Lu, H., Wu, Y., Li, Y. and Liu, Y. (2017). Effects of meteorological droughts on agricultural water resources in southern China. *Journal of Hydrology*. 548: 419-435. <https://doi.org/10.1016/j.jhydrol.2017.03.021>.
- Mariano, D.A., Santos, C.A.C.D., Wardlow, B.D. anderson, M.C., Schiltmeyer, A.V., Tadesse, T. and Svoboda, M.D. (2018). Use of remote sensing indicators to assess effects of drought and human-induced land degradation on ecosystem health in Northeastern Brazil. *Remote Sensing of Environment*. 213: 129-143. <https://doi.org/10.1016/j.rse.2018.04.048>.
- Mondol, A.H., Ara, I. and Das, S.C. (2017). Meteorological drought index mapping in Bangladesh using standardized precipitation index during 1981-2010. *Advances in Meteorology*. 2017(4642060): doi: 10.1155/2017/4642060.
- Msowoya, K. and Madani, K. (2016). Climate change impacts on maize production in the warm heart of Africa. *Water Resources Management*. 5299-5312. <https://doi.org/10.1007/s11269-016-1487-3>
- Mulinde, C., Majaliwa, J.G.M., Twinomuhangi, R., Mfitumukiza, D., Komutunga, E., Ampaire, E., Asimwe, J., Van Asten, P. and Jassogne, L. (2019). Perceived climate risks and adaptation drivers in diverse coffee landscapes of Uganda. *NJAS-Wageningen Journal of Life Sciences*. 88: 31-44. <https://doi.org/10.1016/j.njas.2018.12.002>.
- Nagasha, J., Ocaido, M. and Bwanga, E.K. (2019). Attitudes, practices and knowledge of communities towards climate change around Lake Mburo National Park Uganda: A gender centered analysis. *African Social Science Review*. 10(1): 39-58.
- NECOC. (2017). *Risk and Vulnerability Profile for Mbarara District*.
- Okal, H.A., Ngetich, F.K. and Okeyo, J.M. (2020). Spatio-temporal characterisation of droughts using selected indices in Upper Tana River watershed, Kenya. *Scientific African*. 7: e00275. <https://doi.org/10.1016/j.sciaf.2020.e00275>.
- Prathima, T., Prasanna, A. L., Subramanyam, G. and Madhuri, C.V. (2023). Assessment of drought in Andhra Pradesh using different meteorological drought indices. *Agricultural Science Digest-A Research Journal*. 1-6. <https://doi.org/10.18805/ag.d-5687>.
- Rwamigisa, P.B. (2019). *Agriculture in Uganda/ : Performance and policy implementation*. August. pp 1-27.
- Segurado, P., Branco, P., Jauch, E., Neves, R. and Ferreira, M.T. (2016). Sensitivity of river fishes to climate change: The role of hydrological stressors on habitat range shifts. *Science of the Total Environment*. 562: 435-445. <https://doi.org/10.1016/j.scitotenv.2016.03.188>.
- Shobanadevi, C., Elangaimannan, R. and Vadivel, K. (2022). Screening of blackgram genotypes for drought tolerance using PEG (Polyethylene glycol) induced drought stress at seedling stage. *Legume Research*. 45(8): 968-973. <https://doi.org/10.18805/LR-4535>.

- Steward, P.R., Dougill, A.J., Thierfelder, C., Pittelkow, C.M., Stringer, L.C., Kudzala, M. and Shackelford, G.E. (2018a). Agriculture, ecosystems and environment the adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments: A meta-regression of yields. *Agriculture, Ecosystems and Environment*. 251: 194-202. <https://doi.org/10.1016/j.agee.2017.09.019>.
- Steward, P.R., Dougill, A.J., Thierfelder, C., Pittelkow, C.M., Stringer, L.C., Kudzala, M. and Shackelford, G.E. (2018b). The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments: A meta-regression of yields. *Agriculture, Ecosystems and Environment*. 251: 194-202. <https://doi.org/10.1016/j.agee.2017.09.019>.
- Surendra, S.C., Garg, P.K., Ghosh, S.K. (2012). Mapping of agriculture drought using remote sensing and GIS. *International Journal of Scientific Engineering and Technology*. 1(4): 149-157.
- Tesfaye, K., Kruseman, G., Cairns, J.E., Zaman-Allah, M., Wegary, D., Zaidi, P.H., Boote, K.J., Rahut, D. and Erenstein, O. (2018). Potential benefits of drought and heat tolerance for adapting maize to climate change in tropical environments. *Climate Risk Management*. 19: 106-119. <https://doi.org/10.1016/j.crm.2017.10.001>.
- Tigkas, D., Vangelis, H. and Tsakiris, G. (2015). DrinC: A software for drought analysis based on drought indices. *Earth Science Informatics*. 8(3): 697-709. <https://doi.org/10.1007/s12145-014-0178-y>.
- Twongyirwe, R., Mfitumukiza, D., Barasa, B., Naggayi, B.R., Odongo, H., Nyakato, V. and Mutoni, G. (2019). Perceived effects of drought on household food security in South-western Uganda: Coping responses and determinants. *Weather and Climate Extremes*. 24. <https://doi.org/10.1016/j.wace.2019.100201>.
- W.M.O. (1987). Standardized precipitation index user guide. *Journal of Applied Bacteriology*. 63(3): 197-200.
- Wakabi, P. (2016). Maize training manual for extension workers in Uganda partners. *Maize Training Manual for Extension Workers in Uganda Partners*. 59.
- Webb, N.P., Marshall, N.A., Stringer, L.C., Reed, M.S., Chappell, A. and Herrick, J.E. (2017). Land degradation and climate change: Building climate resilience in agriculture. *Frontiers in Ecology and the Environment*. 15(8): 450-459. <https://doi.org/10.1002/fee.1530>.
- Woods, J., Wilson, J. and Runkle, J. (2008). Influence of climate on butterfly community and population dynamics in western Ohio. *Environmental Entomology*. 37(3): 696-706. [https://doi.org/10.1603/0046-225X\(2008\)37\[696:IOCOBC\]2.0.CO;2](https://doi.org/10.1603/0046-225X(2008)37[696:IOCOBC]2.0.CO;2).
- Zziwa, E., Mpairwe, D., Mugasi, S.K. and Laswai, G.H. (2015). Beef Production practices and responses to climate change in the rangelands of Lake Victoria Basin in Uganda. *International Journal of Agriculture and Forestry*. 5(2): 121-130. <https://doi.org/10.5923/j.ijaf.20150502.05>.