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RESEARCH

Farmers' perceptions of climate change, long-term variability and trends in rainfall in Apac district, northern Uganda

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Abstract

Background: Climate change poses severe threats to smallholder farmers' agricultural livelihoods and food security in Sub Saharan Africa. Understanding long-term rainfall trends of variability and extremes at local scales and perceptions regarding long-term changes in climate variables is important in planning appropriate adaptation measures to climate change. This paper examines the perception of farmers in Apac district regarding long-term changes in climate variables and analyzes the trend of occurrence in seasonal and annual rainfall in Apac district, northern Uganda. A cross-sectional survey design was employed to collect data on farmers' perceptions regarding long-term changes in climate from 260 randomly selected smallholder farmers' households across two sub-counties in Apac district by administering semi-structured questionnaires in February 2018. Monthly rainfall data sets from the Uganda Meteorological Authority (UMA) for the period 1980 to 2019 for Apac district were also used to analyze trends of occurrences in seasonal and annual rainfall in the study area. The non-parametric Sequential Mann–Kendall (SMK) tests were employed at a 5% significance level to detect mean seasonal rainfall trends and abrupt change points.

Results: The majority of the respondents (87%) perceived a decrease in precipitation over the past 39 years. The plot of forward regression $u(t_i)$ values and backward regression $u'(t_i)$ values showed interactions indicating rainfall trends, rainfall lower and upper limits and abrupt change points in the different cropping seasons. Analysis of historical series of mean monthly and annual rainfall showed an abrupt change in rainfall in March, April, May (MAM) season in 1982. Although the September, October and November (SON) season did not show a significant abrupt change, there was a significant ($p < 0.05$) increase in rainfall above the upper limit from 1994 to date.

Conclusion: The mean seasonal rainfall for MAM and SON cropping seasons in Apac district were highly variable from different time points within the past 39 years (1980–2019), while June, July, and August (JJA) did not realize a significant change in rainfall within the same study period that the two cropping seasons (MAM and SON) in the district experienced remarkable variations in rainfall. This, therefore, provides a basis for the government to strengthen the provision of an effective climate tailored agricultural advisory service to aid farmers' adaptation planning at the local level and to assist smallholder farmers and land-use managers in developing effective adaptation management strategies to the effects of climate change.

Keywords: Rainfall, Abrupt change point, Upper limit, Lower limit, Sequential Mann–Kendall test statistics

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Introduction

The smallholder farming communities in Africa face a wide range of climate change challenges which present in the form of unpredicted weather conditions, extended droughts and floods. Many studies (e.g., Igodan et al. 1990; Mendelsohn. 2006, 2008; Esham et al. 2013) have identified Sub Saharan Africa (SSA) and specifically the East African region (Moore et al. 2012; Waithaka et al. 2013; Onyango et al. 2016) as one of the regions most vulnerable to the negative impacts of climate change compared to other regions. This is because of the low levels of adaptation and/or mitigation capacity and poverty of farmers in SSA (Bagamba et al. 2012; Krämer et al. 2013). Inadequate capacity to adapt to the effects of climate change has resulted in global food insecurity, which remains a worldwide concern for the next 50 years and beyond (Hasegawa et al. 2021). The study of precipitation trend over the African continent reveals that while there is a statistically significant increasing annual precipitation trend over most parts of West Africa, the horn of Africa, which includes the East African Region, shows a significantly decreasing precipitation trend (Omondi et al. 2014). The major drivers of these inter-annual climate variations in Africa include El Nino South Oscillation (ENSO), which results from large-scale changes in Sea Surface temperatures (SST) over the tropical Pacific Ocean that influence climatic conditions over much of the tropics and sub tropics.

The tropical East African region experiences much variation in the distribution of precipitation resulting in a complex seasonal cycle. Many parts of the region experience two peaks of rainfall seasons that are normally associated with solar heating maxima in the equinox seasons, SST forces, topography and teleconnections to the West African and Indian monsoon systems (Cook et al. 2013). The Inter-Tropical Convergence Zone (ITCZ) plays a great role in determining rainfall patterns in East Africa (Phillip et al. 2000) which is explained by the movement of the overhead sun over the equator. The sun passes overhead the equator twice a year, making most parts of the East African region experience a bimodal rainfall regime. The first season occurs from March to May and the second season from October to December. These two rainy seasons come with the north-easterly and south-easterly winds originating from the Indian Ocean (Ogallo 1988; Mutai et al. 1998).

In Uganda, particularly in the northern part, the period between the first season and the onset of the second season is short, making it considered a unimodal rainfall regime (Mubiru et al. 2012). Rains in northern Uganda usually start as early as the third week of March. According to Campozano et al. (2016), unimodal rainfall regimes in East Africa are as a result of the orographic effect which occurs mainly at the extremes of the water basins. For areas near the equator, the seasonal pattern generally follows the bimodal system and tends to be a unimodal system with increasing distance from the equator (Conway et al. 2005; Asadullah et al. 2008). Northern Uganda is 219.5 km away from the equator and, on the higher side of the Lake Victoria basin (UBOS 2016), is expected to have a unimodal rainfall regime. The orographic effect from the Lake Victoria basin to the highlands of northern Uganda also puts the region on the unimodal rainfall regime since it is located at the edge of the basin.

The unimodal rainfall regime of northern Uganda experiences three cropping seasons, the first begins in March, through April and ends in May (MAM); the second begins in June, July and ends in August (JJA) while the third is from September, through October to end of November (SON) (Funk et al. 2012; Mubiru et al. 2012). The dry season is felt in December, January up to the end of February. Inter-annual variation in climate includes droughts, floods, variation in the timing of onsets and cessation of rainy seasons, uncertain rainfall durations and seasonal precipitation. A study conducted in northern Uganda by USAID in 2014 reveals that farmers perceive the onset of the rainy season to delay compared to the past, while cessation of the rainy season arrives earlier, with fewer rainy days and sometimes high-intensity rainfall resulting in floods (USAID 2014).

Previous studies on inter annual rainfall variations in the East African region made use of the regional indices which may not necessarily capture climate events over local scales such as in northern Uganda due to the influence of many local factors (Ogwang et al. 2017; Mubiru et al. 2012) yet climate change adaptation needs are location specific (Atube et al. 2021). The lack of information on climate events at the local scale has had adverse effects on smallholder farmers who depend on rainfall to supply the required water for their small farms. The generation of agronomically relevant seasonal rainfall characteristics is important in enhancing knowledge and guiding decisions on climate change adaptation and mitigation measures. This is particularly important for Apac district which is located in the cattle corridor where there is a high incidence of poverty and whose farming population are predominantly smallholders who depend on rain fed agriculture for their livelihoods. This paper explores farmers' perceptions of climate change and analyzes the variability and trends in overall annual and seasonal rainfall patterns for the months of March–April–May (MAM), June–July–August (JJA) and September–October–November (SON) in Apac district, Northern Uganda over the period 1980 to 2019. This information is key in designing response measures to enhance farmers' preparedness and early warning systems. The findings will also help formulate effective smallholder farmers' adaptation at the local level to reduce climate change-related risks.

Methodology

Study area

The study was conducted in Apac district, located in northern Uganda (Fig. 1). The district covers 3,908 km^2, of which swamps and water bodies cover 9% while 15% is covered by forests, leaving 2970km^2 for farming and human settlement (UBOS 2016). The district lies between longitudes 32° E and 34° E and latitudes 2° N and 3° N and is bordered by Lake Kwania and river Nile in the south. Apac district is located in the cattle corridor that stretches from Southwestern to northeastern Uganda and is dominated by pastoral rangelands (Nimusiima et al. 2013). The area is characterized by a uni-modal rainfall pattern. The annual rainfall total is about 1,330 mm, which falls predominantly from April to November, with peaks in April and October. The dry season is from December to March and the average monthly minimum and maximum temperatures are 17 °C and 29 °C, respectively (UBOS 2016). The farming system in Apac district is predominantly mixed small-scale cropping and livestock rearing (UBOS 2014; 2017). The dominant vegetation cover in the district is of the dry savannah type comprising mainly *Hyparrhenia rufa* (Nees) Stapf, *Terminalia superba* Engl. & Diels, *Acacia hockii* De Wild and *Vitellaria paradoxa* C.F.Gaertn. It also has isolated riverine vegetation along river Nile and other areas dominated by wetland plants (UBOS 2016; NEMA 2012).

Data collection

Data on perception

We collected primary data on perception using household surveys. The target population of smallholder farmers was selected using a multistage sampling technique. First, Apac district was purposively selected based on the limited researched information regarding smallholder farmers' perception of climatic change and the highly agrarian nature of their population and location in the cattle corridor. The livestock sector in this study is key because of its contribution to Uganda's growing economy, contributing an average of 4.2% to the national Gross Domestic Product (GDP) in recent years (UBOS 2017).

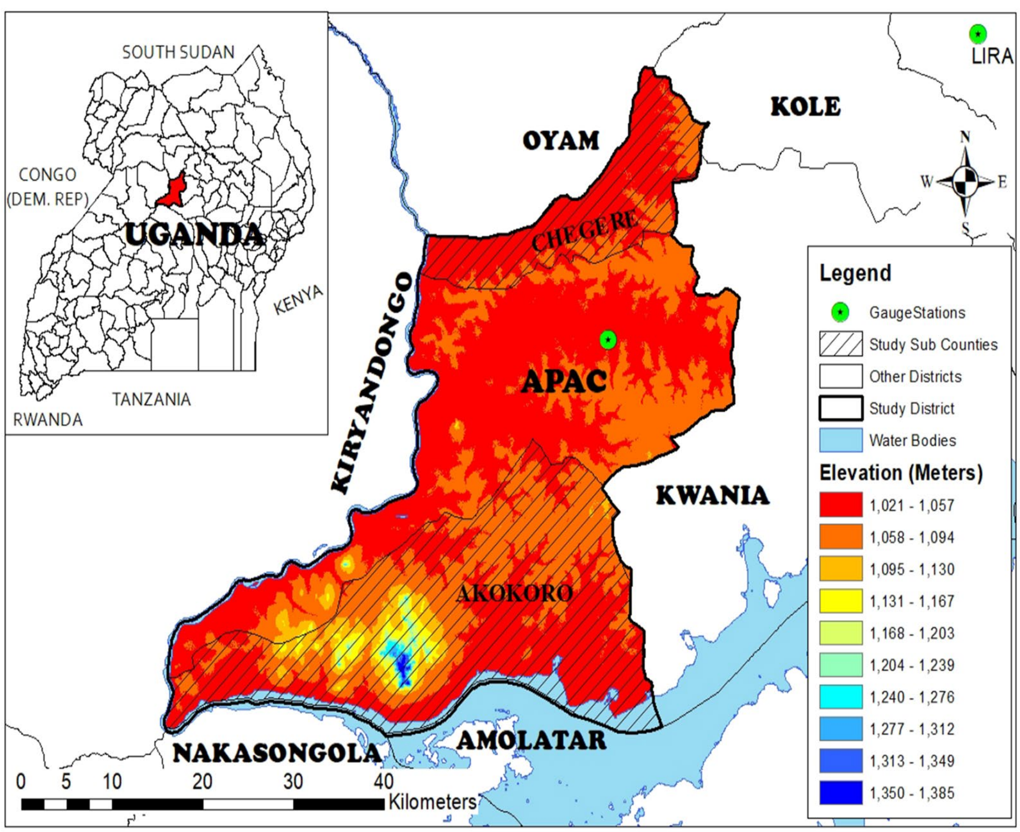

Fig.1 Location of study areas in Apac district, northern Uganda

From the district, two sub-counties; Akokoro and Chegere were randomly selected. In each of the selected Subcounties, two parishes were randomly selected totaling to four parishes. From each of the parishes, one village was randomly selected making a total of four villages for the entire study. With the help of the village local leaders, a sample frame from each village was generated, from which a sample of 65 households per village was selected using a simple random sampling technique. The four villages collectively had 800 smallholder farmer households. Therefore, using the Krecjie and Morgan (1970) table gave a sample size of 260 households. Finally, 260 households were randomly and proportionally selected from the four villages. A cross-sectional survey (conducted from December 2018 to May 2019) was employed to collect primary data from farming household heads. The survey was piloted at Paicho Sub County in Gulu district with 20 farmers (13 males and seven females). The surveys were carried out by trained data enumerators. The primary data obtained included farmers' perceptions of key aspects related to rainfall variability. During the interviews, we explored farmers' perception of climate change over the past 39 years (1980–2019). Respondents were asked whether they had noted any changes (increase, decrease, no change) in the weather pattern over the last three decades.

Climate data

The historical daily rainfall totals that were summed up to generate monthly rainfall totals for Apac were provided by the Uganda National Meteorological Authority (UNMA) for the period 1980–2019. This methodological approach was also previously used by Ongoma et al. (2018) to establish trends in time series of rainfall indices obtained from daily rainfall series over East Africa. The data for this study was grouped into three different rain seasons; first (March–April-May), second (June-July–August) and third rainy seasons (September–October-November). To ensure the reliability of the rainfall records used in the study, we extracted rainfall records from Lira district rain gauge, the next nearby district (about 69 km), with properly recorded rainfall records for the entire study period. We ran a correlation analysis for Apac- Lira rainfall. In the correlation, we compared month by month e.g. January Rainfall for Lira was correlated to January rainfall for Apac, etc. Then the average monthly and the seasonal (MAM, JJA and SON). They were all above 0.7, meaning they were significantly related (Table 5 in Appendix).

Data analyses

Primary data

Descriptive statistics using means, frequencies and percentages were used to describe farmers' perception of climate shocks.

Estimation of missing rainfall data

The level of advancement in technology and changes in observation routines of rainfall records can affect the quality of the meteorological records. Additionally, other challenges such as political instability, poor maintenance of weather stations and inadequate technical capacity have resulted in poor record keeping and inconsistencies in Uganda's meteorological data (Anderson et al. 2009). This situation has led to gaps in rainfall data for Apac, which need to be addressed. In this study the arithmetic mean method was used to estimate missing monthly rainfall data since the normal monthly precipitation of similar months were within the range of 10% of the normal monthly precipitation of the missing monthly data (Chow et al. 1988).

Rainfall trend analyses

A sequential non-parametric Mann–Kendall (SMK) test was employed on the monthly average data sets to identify discontinuities and abrupt change points that indicate the starting year of the trend in the data series. SMK is a valid and widely used method for detecting trends in climatic time series data (Chatterjee et al. 2014). It is most preferred because of its insensitivity to outliers and tendency to take care of the skewed distribution of data. The MK test statistic also does not depend on the magnitude of data missing values and space–time of monitoring (Ongoma et al. 2018). The significance of the trend was determined at 95% confidence interval.

To prevent seasons of maximum variance from being pre-dominant, data were normalized prior to analysis. The standardized rainfall anomaly z was computed from:

$$Z = \frac{X - \overline{X}}{S_d} \tag{1}$$

where X denotes observed MAM, JJA and SON rainfall,

Xbar is the long term mean for MAM, JJA and SON rainfall.

S_d is the standard deviation in the MAM, JJA and SON rainfall.

The value of Z provides instantaneous information about the deviation from the mean.

Temporal variability of the seasonal rainfall pattern

The seasonal rainfall totals were normalized following Eq. 1 for several reasons: First was to identify years with either excess or suppressed rainfall over the study period during the rainfall seasons in the study area, second to present the temporal variations of indices from which extreme peak years were identified and lastly was to obtain seasonal rainfall indices on an interannual scale.

Sequential Mann–Kendall test statistic

The Sequential version of the Mann–Kendall test statistic (Sneyres 1990) on time series x_i detects recognized events or change points in long-term time series. The Sequential Mann–Kendall test was computed using the ranked values, y_i of the given time series $(x_1, x_2, x_3, \ldots x_n)$. The magnitudes of $y_i (i = 1, 2, 3, \ldots n)$ are compared with $y_j (j = 1, 2, 3, \ldots, k - 1)$. For each comparison, the cases where $y_i > y_j$ were counted and denoted by n_i.

A statistic t_i was defined as:

$$t_i = \sum_{j=1}^{k} n_i \tag{2}$$

The distribution of test statistics t_i has a mean specified as:

$$E(t_i) = \frac{i(i-1)}{4} \tag{3}$$

and variance specified as

$$Var(t_i) = \frac{i(i-1)(21+5)}{72} \tag{4}$$

The sequential values of a reduced or standardized variable, called statistic $u(t_i)$ was calculated for each of the test statistic variable t_i as follows:

$$u(t_i) = \frac{[t_i - B(t_i)}{\sqrt{\mathrm{var}(t_i)}} \tag{5}$$

while the forward sequential statistic $(u(t_i))$ was estimated using the given time series $(x_1, x_2, x_3, \ldots x_n)$, the values of the backward sequential statistic $(u'(t))$ were computed in the same manner but starting from the end of the series. When estimating the $u'(t)$, the time series is sorted so that the last value of the original time series comes first $(x_1, x_2, x_3, \ldots x_n)$. The sequential version of the Mann–Kendall test statistic allows detection of the approximate beginning of a developing trend. When $u(t_i)$ and $u'(t)$ curves are plotted, the intersection of the curves $u(t_i)$ and $u'(t)$ locates the approximate potential trend turning point. If the intersection of $u(t_i)$ and $u'(t)$ occurs within + or − 1.96 (5% level) of the standardized statistic, a detectable change at that point in the time series can be inferred. Moreover, if at least one value of the reduced variable is greater than a chosen level of significance of Gaussian distribution, the null hypothesis (H_0: Sample under investigation shows no beginning of a new trend) is rejected.

Results and discussion

Farmers' perceptions of climate change

Farmers generally perceived climate change in terms of extreme weather events, number of pest and disease attacks, availability of rainwater, the intensity of rain, number of rain days, duration of rain period, amount of rain, frequency of rain, variation in the onset of rain period, variation in cessation of rain period and the number of hot days/drought. The results of the study showed that almost 88% representing 232 farmers/respondents interviewed across the district perceived an increase. In comparison, only 6% perceived a decrease in the

Table 1 Farmer's perceptions on climate change in Apac district

Response	Increased		Decreased		No change	
	N	%	N	%	N	%
No. of extreme events	191	72.1	38	14.4	36	13.6
No. of pest and disease attacks	227	85.6	19	7.1	19	7.2
Availability of rain water	23	8.6	208	78.5	34	12.8
Intensity of rain	24	9.0	216	81.5	25	9.4
No. of rain days	7	2.6	233	87.9	25	9.4
Duration of rain period	19	7.1	201	75.8	45	17
Amount of rain	14	5.3	230	86.8	21	7.9
Frequency of rain	10	3.7	231	87.2	24	9.1
Variation in onset of rain period	124	46.8	115	43.2	26	9.8
Variation in cessation of rain period	106	40	145	54.7	14	5.3
No. of hot days/Drought	232	87.5	16	6.1	17	6.4

number of hot days/droughts over the past three decades (Table 1). A total of 6% of farmers perceived no change in hot days. The majority of respondents perceived an increased number of pest and disease attacks (86%), an increased number of extreme weather events (72%), while 47% reported increased variation in the onset of rain period. The majority of respondents reported a decrease in the number of rain days (88%), frequency of rain (87%), amount of rain (87%), the intensity of rain (82%), availability of rainwater (79%), duration of rain period (76%), (Table 1). Only a few (between 5 to 14%) farmers reported no change in climate for the past three decades. The results of this study imply that farmers perceive a change in climate, as most (> 80% of the farmers) interviewed perceived a decreasing trend in the amount and intensity of precipitation. This corroborates the findings of Oluwatimilehin and Ayanlade (2021), Juana et al. (2013) and Fosu-Mensah et al. (2012), who reported that the majority of the respondents in Ondo and Ogun states, Nigeria, in Ghana and in Eastern Saloum in Senegal, respectively were all aware of changes in long term climate patterns particularly decreased precipitation. Late onset and early cessation of rainfall, decrease in duration of rainfall and general unpredictability of rainfall by smallholder farmers have also been reported in existing literature (Abid et al. 2015; Chepkoech et al. 2018; Asare-Nuamah et al. 2019; Adaawen 2021). Analysis of the relationship between farmers' perception of climate change and the age of household heads (Table 2 in Appendix) showed no significant association between age and all the parameters of farmers' perception of climate change. Thus, farmers' responses were not age-dependent.

To verify the farmers' perceived long-term change in rainfall, the historical annual mean rainfall data for the study area from 1980 to 2019 (39 years) were analyzed.

Seasonal rainfall patterns of the study area

The normalized indices for March, April, May (MAM), June, July, August (JJA) and September, October, November (SON) seasons generated from consistent seasonal rainfall totals over the study period are presented in Table 3 in Appendix. The study finding showed that there was variability in MAM, JJA and SON rainfall seasons and that they were quite independent of one another. For this reason, the seasonal rainfall pattern of the three rainfall seasons was presented separately. To understand the rainfall pattern of MAM over Apac district, the standard anomaly of MAM rainfall (Fig. 2) was examined. Results show that the highest mean MAM rainfall over the period 1980–2019 was observed in 1983 (extremely wet), while the least amount was noted in 2000 (extremely dry). However, based on the standard deviation of MAM rainfall of ≥ 1 (for wet years) and ≤ 1 (for dry years) (Ogwang et al. 2018), three wet years were observed over the study period; while two dry years were noted for the same study period (Fig. 2).

The standard Anomaly of JJA rainfall pattern over Apac district was examined, as illustrated in Fig. 3. The results indicate that the highest mean JJA rainfall over Apac district in the period 1980–2019 was observed in 1994 and 2007, which seem to have received the same amounts of rainfall (extremely wet), while the least amount was noted in 2019 (extremely dry). However, based on the standard deviation of JJA rainfall of ≥ 1 (for wet years) and ≤ 1(for dry years) (Ogwang et al. 2018), three wet years were observed during JJA over the study period, while three dry years were noted for the same study period (Fig. 3).

The standard anomaly of SON rainfall (Fig. 4) showed that the highest mean SON rainfall over the period 1980–2019 was observed in 2019 (extremely wet), while the least amount was noted in 1981 (extremely dry year). This corroborates with the findings of Wainwright et al. (2021), which revealed that 2019 was one of the wettest short rain seasons since 1985. Based on the standard deviation of SON rainfall of ≥ 1 (for wet years) and ≤ 1 (for dry years), respectively, as used by Ogwang et al. (2018), four wet years were observed over the study period, while three dry years were noted for the same study period (Fig. 4).

The analysis of the temporal annual average rainfall over Apac district (Fig. 5) showed much annual variability within the study period, with the highest observed annual average (computed from the monthly totals) rainfall in 2011 at 149 mm, while the lowest was in 1989 at 95 mm. This finding is consistent with those of Mubiru et al. (2018), who investigated climate trends, risks, and coping strategies in Rakai and Hoima in southwestern and western Uganda. Their findings revealed that rainfall has become more variable and erratic, negatively impacting soil moisture content and availability, leading to reduced crop yields or total crop failure.

Seasonal rainfall trend of the study area

The Mann–Kendall analysis of mean MAM, JJA and SON rainfall over Apac from 1980 to 2019 is illustrated in Figs. 6, 7, 8. The blue lines above (UL) and below (LL) and the dashed (dotted) lines represent critical values of 95% confidence interval. The sequential Mann–Kendall test statistics are denoted as the forward regression (FR) and backward regression (BR).

MAM

Results of the Sequential Mann–Kendall test statistic for MAM seasonal rainfall over Apac (Fig. 6) considering the plot of $u(t_i)$ and $u'(t_i)$ values for each of the months of the season (MAM) clearly indicated a decreasing trend in the mean MAM seasonal rainfall between 1982–1995. It also showed that from 1980 to 1982, MAM seasonal rainfall varied within the mean. Thereafter, there was an abrupt change in trend in 1983, followed by a steady decline in rainfall trend in MAM. This decreasing trend became significant in 1985, 1999 and 2011. After 2011, the seasonal rain showed an increasing trend which was not significant but continued up to the end of the study period (see Table 4 in Appendix). The changes in MAM rain season were also documented by Mubiru et al. (2012) where they note that the unseasonal periods (3–4 weeks) of no rain are becoming common in the unimodal rainfall receiving areas such as northern Uganda. The decreasing trend followed by a recent increase in MAM season rainfall is linked to changing season length (Wainwright et al. 2019) and changes in zonal winds (Walker et al. 2020). According to Hoell et al. (2017), the decline in MAM season rainfall could also be due to changes in the Indo-Pacific Ocean which drives an anomalous overturning mass circulation of dry wind over the East African region leading to increased subsidence and long-term drying over East Africa. Other earlier studies (e.g., Okoola 1996; Camberlin et al. 2003) have also associated these variations and abrupt changes in rainfall in Uganda with the large-scale global systems that control weather such as the El Nino South Oscillation (ENSO) in the pacific Ocean, the Indian Ocean Dipole (IOD), the tropical cyclones in the Indian Ocean and monsoon winds over the East Africa region.

JJA

The forward $u(t_i)$ and backward $u'(t_i)$ regression plots for the June, July and August season rainfall (Fig. 7) displays variability within the mean with no decreasing nor increasing trend in the seasonal rainfall. Overall, there was neither observed increase nor decrease in JJA seasonal rainfall trend. The pattern (in Fig. 7) shows variation within the mean monthly rainfall of the study area. A study of the East African seasonal rainfall (Ntale et al. 2003) revealed a narrow coastal band starting from Madagascar, reaching the northeastern coast of Africa and extending to the west coast of India, which is correlated with the SST. This is brought about by a buildup of cold Sea Surface Temperatures (SSTs) during JJA in the Indian Ocean, which probably reduces the amount of moisture in the south easterlies, resulting in more or less average rains received in the region during JJA.

SON

Results from Mann-Kendal analysis (Fig. 8) indicated a general increasing trend in the SON seasonal rainfall right from 1980 up to 2019. The increasing trend became significant in 1988 and thereafter decreases briefly till around 1991 and increases again till the end of the study period. The increase in rainfall trend was significant from 1986 up to the end of the study period, as shown by the curve beyond the significance level ($p < 0.05$). Overall, SON seasonal rainfall over the study area displays an increasing trend for the study period. This finding could be explained by a study by Ogwang et al. (2017) which indicated a close relationship between SON rainfall anomaly over Uganda and the SON Sea Surface Temperatures (SST) anomaly over the Indian Ocean which captures the Indian Ocean Dipole (IOD) pattern, with significant positive correlations in the western sector of the Indian Ocean and South Eastern part of the African continent. The findings of Wainwright et al. (2021) in their study of extreme rainfall in East Africa also revealed that positive IOD events tend to lead to enhanced rainfall over East Africa. According to Black et al. (2005), warmer Indian Ocean SST develops in the western region during extreme positive IOD events and colder SST in the East. This makes much rainfall move with the warm waters westwards towards the East African region resulting in higher than average rainfall and floods in the East Africa region.

On the other hand, in the east of the Indian Ocean, SST will be colder than normal, resulting in reduced rainfall. This means that the SON seasonal rainfall pattern is greatly influenced by the status of the IOD determined by the Indian Ocean Surface temperatures (temperature of the water surface of the Indian Ocean). Behera et al. (2005) noted that the IOD has an overwhelming influence on the East African short rains from October to December.

The annual (Monthly totals) average precipitation trend over Apac district from 1980–2019 (Fig. 9) shows a generally increasing trend of about 116 mm in 1980 to 128 mm in 2019, contrary to the perception of farmers' of generally decreasing rainfall trend in Apac district. Farmers' perception of a declining rainfall trend could be due to abnormal rainfall onset, amount and cessation, and the increasing mid-seasonal droughts (Mubiru et al. 2018).

Limitations of the study

This study used only one rain gauge station, meaning that spatially distributed precipitation data could be inaccurate. However, this weakness was overcome by

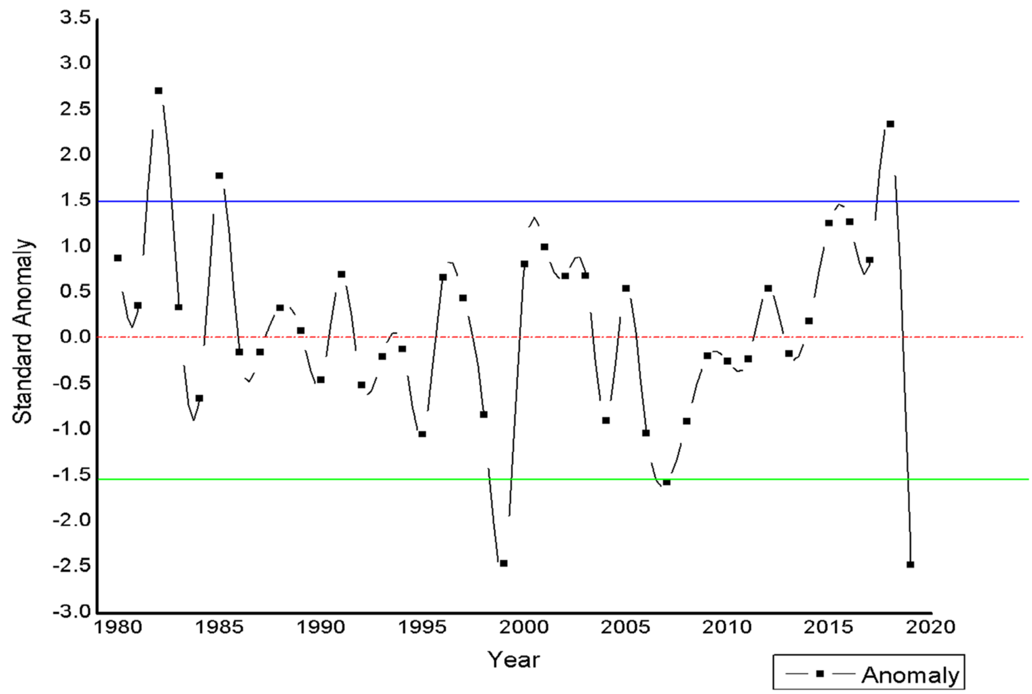

Fig. 2 MAM seasonal rainfall pattern over Apac district, Uganda from 1980 to 2019

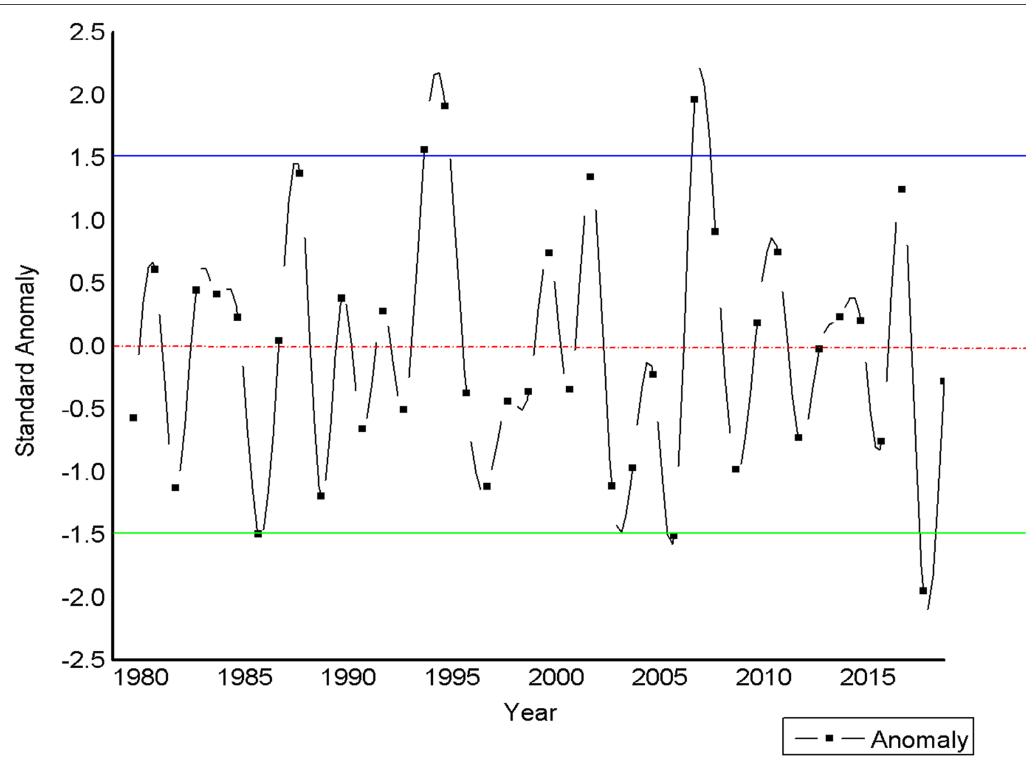

Fig. 3 JJA seasonal rainfall pattern in Apac district from 1980 to 2019

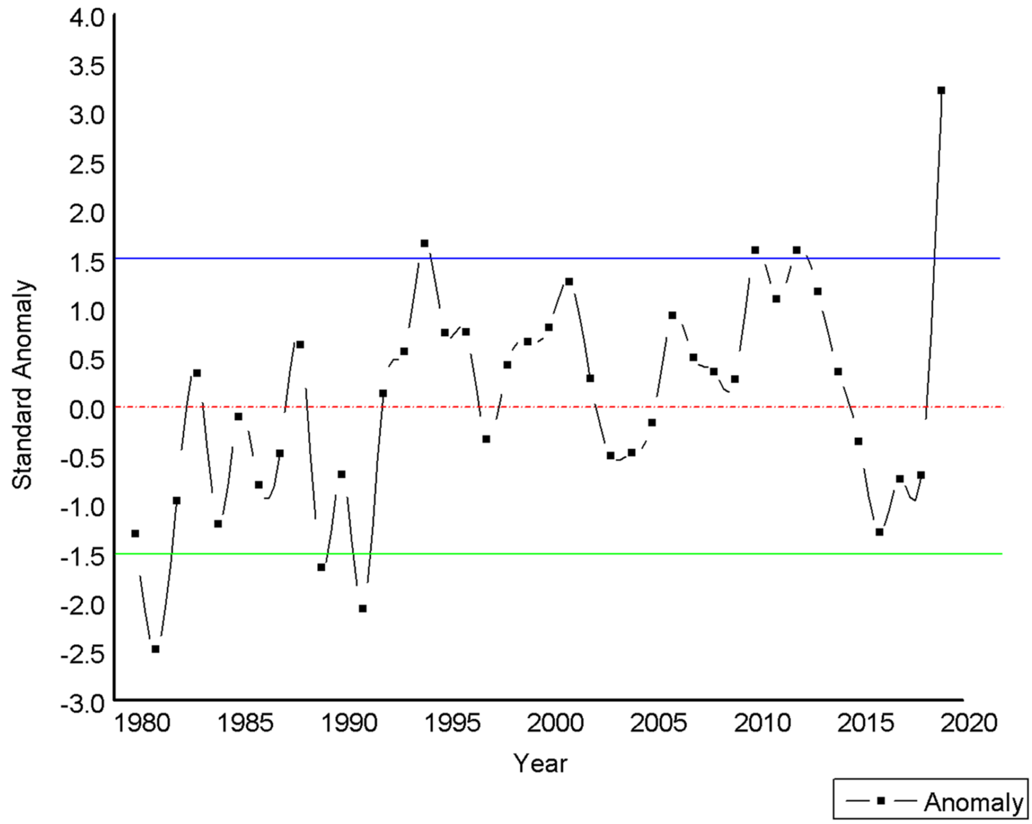

Fig. 4 SON seasonal rainfall pattern in Apac district, Uganda, from 1980 to 2019

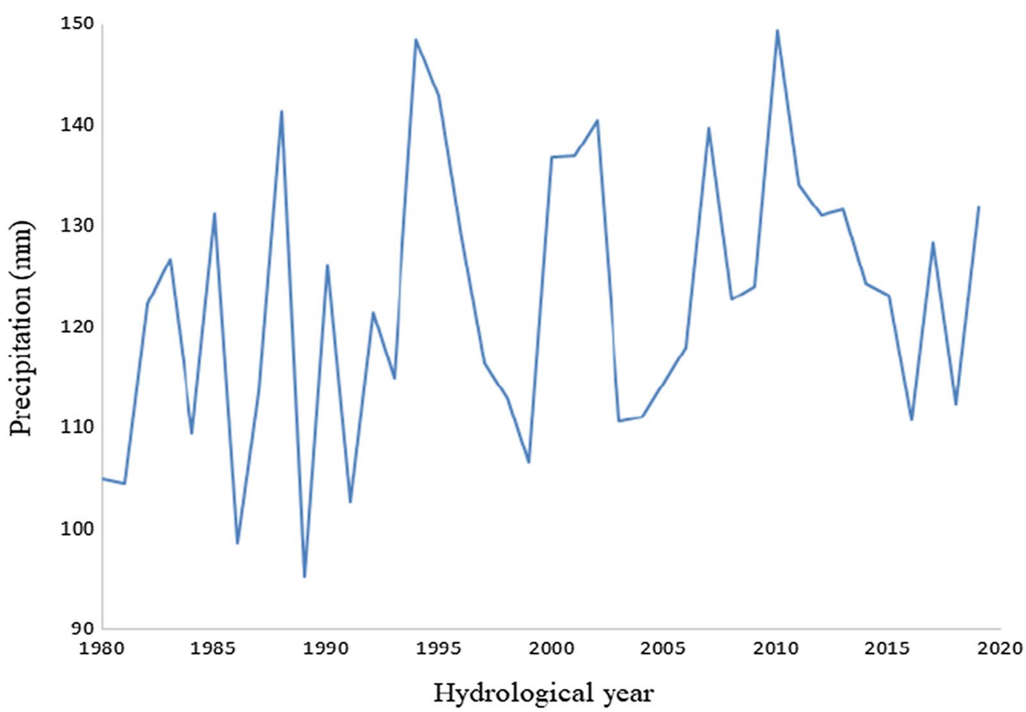

Fig. 5 The annual average (Monthly totals) precipitation pattern over Apac (1980—2019)

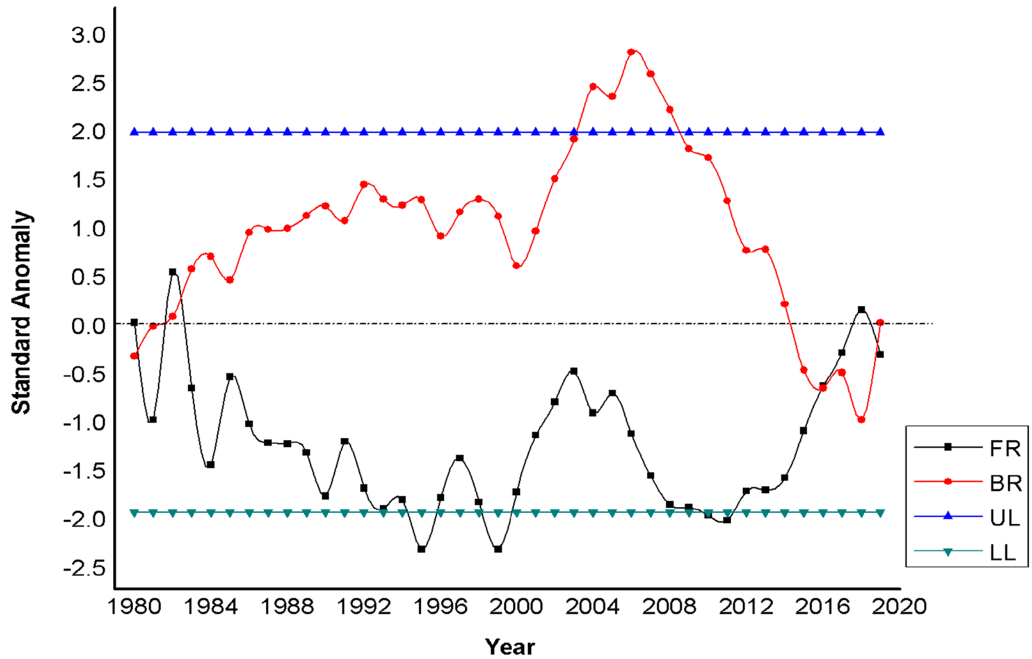

Fig. 6 Changes in average March, April and May (MAM) seasonal rainfall in Apac district (1980-12019) as derived from sequential Mann–Kendall test statistics, $u(t_i)$ forward sequential statistics and $u'(t_i)$ backward sequential statistic. *FR* forward regression, *BR* Backward regression, *UL* Upper limit and *LL* Lower limit

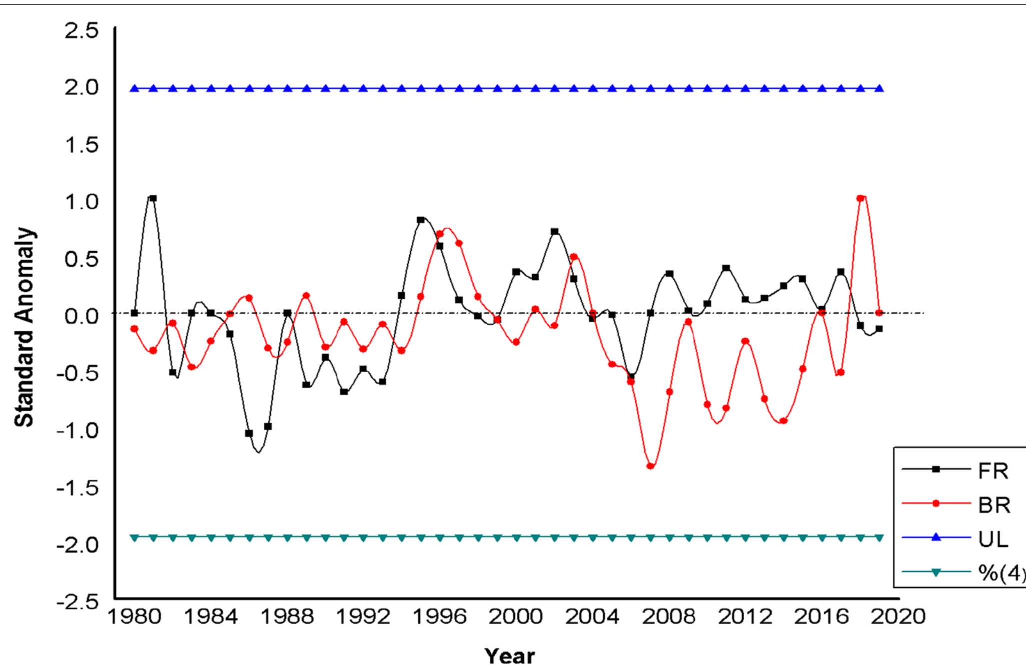

Fig. 7 Change in average June, July and August (JJA) seasonal rainfall in Apac district (1980–2019) derived from sequential Mann–Kendall test statistics, $u(t_i)$ forward sequential statistics and $u'(t_i)$ backward sequential statistic

taking rainfall records for an extended period (Sharma et al. 2016). We also included in the sample individuals who were not yet born at the start of the 39 years under review and therefore had a shorter frame of reference for their 'perceptions of change' than older respondents. This means that those young respondents could have either been referring to their own experience over fewer years in their 'perceptions of climate change', or repeating stories they heard from their elders which may not be as accurate (Additional file 1).

Discussion

The seasonal and interannual climate variability had many adverse effects on the smallholder farming communities in Apac district. The incidences of prolonged droughts in MAM and prolonged/increased rainfall during SON resulted in reduced crop productivity among smallholder farmers due to increased postharvest losses resulting from floods and increased crop pests and diseases evidenced by the locust invasion in 2019. There were notably also increased incidences of flooding of homesteads and gardens, leading to the displacement of homesteads. There were incidences of crop failures during MAM experienced by farmers who planted seeds in early March with the expectation that the season's rains would set on as expected in the early month of March resulting to stunted crops in the gardens. The overwhelming perception of reduced rains (Table 1) by farmers in the three seasons of MAM, JJA and SON is not in agreement with the study findings at both seasonal and annual levels. Using the non-parametric Sequential Mann–Kendall (SMK) tests, this study established that seasonal rainfall pattern (Fig. 4) and trend (Fig. 8) of SON over Apac were above average from 1994 to 2019 and the annual rainfall trend (Fig. 9) had a steady increase. This could be because the rains of MAM season is more agriculturally relevant to the smallholder farmers as it occurs around germination and planting of seeds after the long dry spell of December, January and February while the prolonged and more rainfall is less useful since it interferes with harvesting and postharvest management of the crops. This could be a clear sign of failure by smallholder farmers to adapt to climate change leading to crop failures and reduced productivity. With future projections of increased climate variability in the East African region due to climate change, smallholder farmers should be prepared to adapt for later onset of rains during MAM as experienced in 2000, and more intense rains in SON

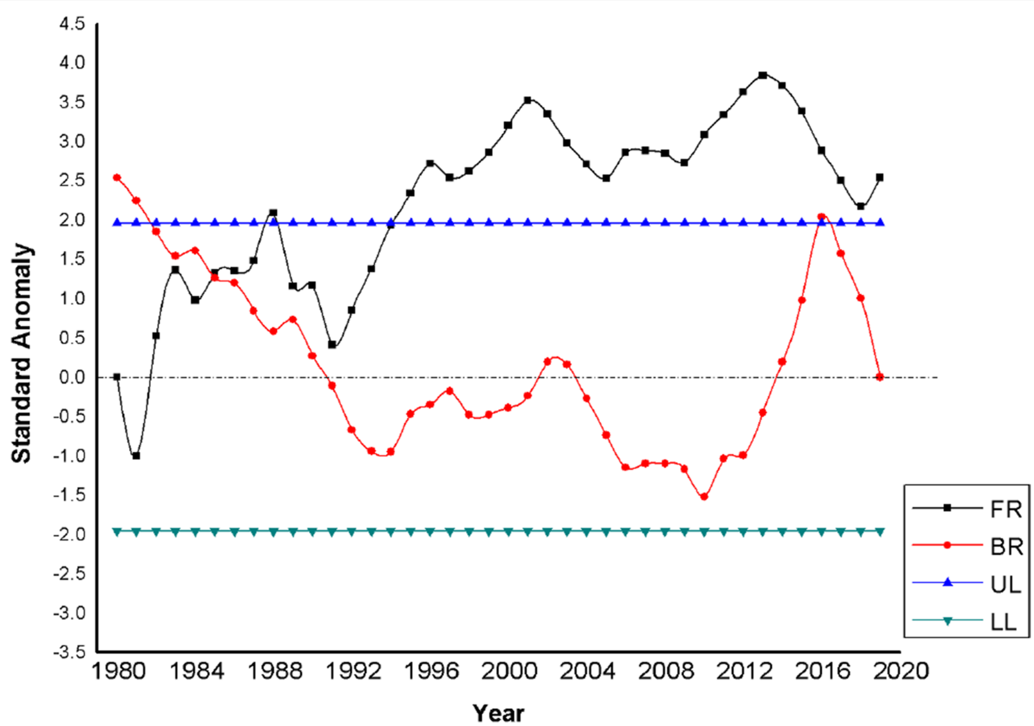

Fig. 8 Change in average September, October and December (SON) seasonal rainfall over Apac district (1980–2019) as derived from sequential Mann–Kendall test statistics, $u(t_i)$ forward sequential statistics and $u'(t_i)$ backward sequential statistic

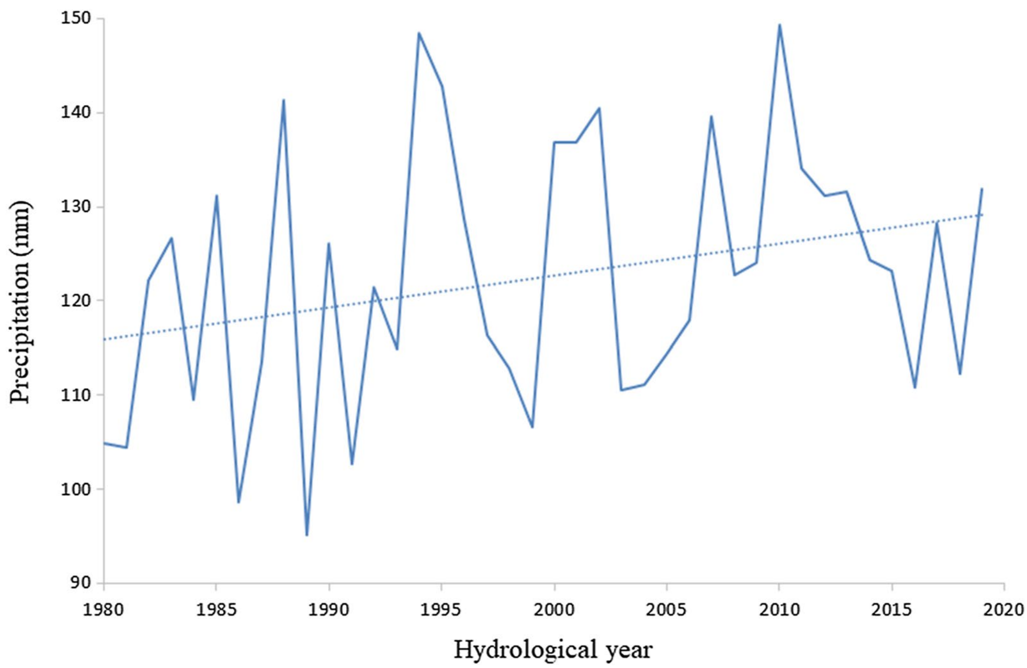

Fig. 9 Annual (Monthly totals) average precipitation trend over Apac district (1980–2019)

as experienced over Apac district from 1994 to its peak in 2019. This situation calls for more effective and efficient weather forecasting to provide early warnings to smallholder farmers to manage the risks of prolonged MAM droughts and SON floods (Additional file 2).

Conclusions

This study analyzed long-term rainfall time series of mean seasonal and annual rainfall in Apac district for 39 years from 1980 to 2019. The study reveals that mean seasonal rainfall for MAM and SON cropping seasons in Apac district showed high variability from different time points within the past 39 years (1980–2019), while JJA has not had a significant change in rainfall within the same study period. Thus, the district's two cropping seasons (MAM and SON) have experienced remarkable variations in rainfall. The first cropping season of MAM has experienced a significant decrease in rainfall, with peaks experienced in 1995, 2009 and 2011 when Apac received rains below the area's expected lower limits. The most significant turning point for the MAM season over the years to start experiencing droughts was in 1982. According to this study, the second cropping season of JJA experienced an insignificant variation in rainfall since the forward regression curve neither went below the lower limit nor the upper limit. That means this season (JJA) has been very supportive of farming in Apac. This study also revealed that the cropping season of SON in Apac generally received much rainfall above the upper limit for most of the period of study (Fig. 4). The wet conditions in SON season that enters deep into the dry months of December, January and February have a strong bearing on the crop farmers who would use the dry period to dry and process their farm produce. The increase of average rainfall within the SON season may have resulted from the positive IOD events leading to enhanced rainfall over the East African and Northern Uganda in particular. The seasonal rainfall information generated in this study offers opportunities to improve on farmer adaptation to the effects of climate change and increase crop yields through incorporation of the seasonal characteristics of the onset, cessation and length of the crop-growing season. This information can also guide agricultural extension messages from extension agents to rural farmers.

Appendix

See Table 2, Table 3, Table 4, Table 5.

Table 2 Chi-square test of association between age group and farmers' perception of climate change in Apac district

Parameter	Age group	Increased		No change		Decreased		Chi-square	p-value
		Freq	Percent	Freq	Percent	Freq	Percent		
No. of extreme events	Youth	85	72.6	13	11.1	19	16.2	4.413	0.353
	Adult	95	70.4	23	17.0	17	12.6		
	Elder	11	84.6	0	0.0	2	15.4		
No. of pest and disease attacks	Youth	96	82.1	8	6.8	13	11.1	6.633	0.157
	Adult	121	89.6	9	6.7	5	3.7		
	Elder	10	76.9	2	15.4	1	7.7		
Availability of rain water	Youth	7	6.0	11	9.4	99	84.6	6.813	0.146
	Adult	16	11.9	21	15.6	98	72.6		
	Elder	0	0.0	2	15.4	11	84.6		
Intensity of rain	Youth	8	6.8	7	6.0	102	87.0	7.386	0.117
	Adult	13	9.6	17	12.6	105	78.0		
	Elder	3	23.1	1	7.7	9	69.0		
No. of rain days	Youth	2	1.7	11	9.4	104	88.9	1.417	0.841
	Adult	5	3.7	13	9.6	117	86.7		
	Elder	0	0.0	1	7.7	12	92.3		
Duration of rain period	Youth	7	6.0	18	15.4	92	78.6	1.032	0.905
	Adult	11	8.1	25	18.5	99	73.3		
	Elder	1	7.7	2	15.4	10	76.9		
Amount of rain	Youth	4	3.4	9	7.7	104	88.9	5.967	0.202
	Adult	9	6.7	9	6.7	117	86.7		
	Elder	1	7.7	3	23.1	9	69.2		
Frequency of rain	Youth	4	3.4	6	5.1	107	91.5	4.821	0.306
	Adult	5	3.7	16	11.9	114	84.4		
	Elder	1	7.7	2	15.4	10	76.9		
Variation in onset of rain period	Youth	58	49.6	6	5.1	53	45.3	5.922	0.205
	Adult	59	43.7	18	13.3	58	43.0		
	Elder	7	53.8	2	15.4	4	30.8		
Variation in cessation of rain period	Youth	41	35.0	6	5.1	70	59.8	3.178	0.529
	Adult	58	43.0	7	5.2	70	51.9		
	Elder	7	53.8	1	7.7	5	38.5		
No. of hot days/Drought	Youth	103	88.0	6	5.1	8	6.8	1.503	0.826
	Adult	117	86.7	10	7.4	8	5.9		
	Elder	12	92.3	1	7.7	0	0.0		

Age group categories are as; Youth = below 36 years old, Adult = 36–65; Elder = over 65 years old

Table 3 Standardized seasonal rainfall indices for MAM, JJA and SON

Year	MAM	JJA	SON
1981	0.887248	− 0.57193	− 1.30008
1982	0.372456	0.609075	− 2.47818
1983	2.718361	− 1.12852	− 0.95953
1984	0.349784	0.445614	0.340675
1985	− 0.64646	0.412922	− 1.19991
1986	1.790135	0.229391	− 0.10672
1987	− 0.14515	− 1.49328	− 0.80022
1988	− 0.14515	0.041169	− 0.48065
1989	0.341782	1.373256	0.625899
1990	0.091054	− 1.19472	− 1.64731
1991	− 0.44241	0.382682	− 0.69243
1992	0.712539	− 0.65448	− 2.06417
1993	− 0.49576	0.278067	0.131766
1994	− 0.18901	− 0.50573	0.561032
1995	− 0.10366	1.56614	1.659955
1996	− 1.03855	1.911861	0.74991
1997	0.671196	− 0.37169	0.761357
1998	0.449808	− 1.11626	− 0.33757
1999	− 0.82517	− 0.43789	0.420805
2000	− 2.45223	− 0.3627	0.661195
2001	0.8259	0.739844	0.802376
2002	1.009945	− 0.34635	1.270753
2003	0.691201	1.350372	0.286302
2004	0.699202	− 1.1089	− 0.50736
2005	− 0.88518	− 0.96669	− 0.47589
2006	0.551166	− 0.22376	− 0.17063
2007	− 1.02255	− 1.50693	0.92734
2008	− 1.56402	1.964168	0.501889
2009	− 0.89319	0.913113	0.354984
2010	− 0.18235	− 0.98222	0.273901
2011	− 0.24369	0.182442	1.590417
2012	− 0.21569	0.746383	1.098093
2013	0.553834	− 0.72804	1.589364
2014	− 0.15967	− 0.02515	1.172499
2015	0.196413	0.234749	0.352123
2016	1.270008	0.200423	− 0.35569
2017	1.282011	− 0.75501	− 1.28768
2018	0.864576	1.247391	− 0.74298
2019	2.348938	− 1.94582	− 0.70483
2020	− 2.4629	− 0.2777	3.220578

Table 4 Change points in seasonal rainfall detected using Sequential Man-Kendall Test for Apac district (Values significant at $p \leq 0.05$)

Season	Detected change points												Remarks
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	
MAM	1981	1982*	2016*	–	–	–	–	–	–	–	–	–	*Significant
JJA	1981	1982	1984	1987	1988	1993	1995	1999	2002	2003	2005	2017	
SON	–	–	–	–	–	–	–	–	–	–	–	–	

Table 5 Correlation coefficients of monthly rainfall records for Apac–Lira districts from the UNMA for the period 1980–2019

Month	Correlation coefficient
January	0.9710
February	0.9272
March	0.9822
April	0.8954
May	0.9455
June	0.7594
July	0.8563
August	0.8150
September	0.9243
October	0.8547
November	0.7914
December	0.9512
Average monthly total	0.7885
MAM	0.9070
JJA	0.8968
SON	0.7618

Abbreviations
UMA: Uganda Meteorological Authority; MAM: March, April, May; JJA: June July August; SON: September, October, November; ADB: African Development Bank; GUREC: Gulu University Research Ethics Committee; IPCC: Inter governmental Panel on Climate Change; UNCST: Uganda National Council of Science and Technology.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s43170-022-00116-4.

Additional file 1. Questionnaire assessing farmers awareness and perception on climate change

Additional file 2. TAMSAT and Recorded rainfall data used for computing correlations in Table 5

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Author contributions
FA, GMM, MN, and IOU participated in designing the study; FA and OGW participated in collecting field data. FA, OGW DMO and GMM participated in analyzing and presenting the data. FA, GMM, BM, MN, DMO and IOU wrote the initial drafts of the manuscript. All the authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Gulu University Research Ethics Committee (GUREC: GUREC -022-19) and the Uganda National Council of Science and Technology (UNCST). Prior to data collection, written informed consent were obtained from all the participants.

Consent for publication
Not applicable.

Conflict of interests
The authors declare no competing interests.

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