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Original Article

Variability and Changes in Climate in Northern Uganda

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ABSTRACT

Variability and changes in climate are generally expected to occur. However, there remain gaps on dynamics of expected regional variations in climatic changes. This study assessed historic and projected climatic conditions up to the year 2033. The study hypothesized that temperature rather than rainfall significantly increased for the period 1980-2010 and rainfall rather than temperature is likely to decrease significantly by 2033 for Gulu District in northern Uganda. To determine historic climatic trends, rainfall and temperature data were obtained from Uganda National Meteorological Authority (UNMA) while for future climate, the PRECIS (Providing Regional Climates for Impact Studies) modelled data based on projected conditions at a 50 km spatial resolution was used. These data sets were subjected to trend analysis and the differences in means were detected at a 95% confidence level. Contrary to the evidences from other empirical studies, results generally indicated decreasing rainfall for the period 1980-2010. However, the decrease was not significant ($P > 0.05$) while both historic mean annual maximum and minimum temperature trends showed a statistically significant increase ($P<0.05$). Projections for 2033 reveal a significant decrease in rainfall ($P < 0.05$) while both maximum and minimum temperature will remain quasi uniform.

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INTRODUCTION

A compelling number of studies globally indicate that variability and changes in climate are generally occurring and severely affecting the poor due to their limited adaptive capacities and systems (FAO, 2008; IPCC, 2007; Kilembe et al., 2012; Sultan et al., 2013; Wang, 2019). In Sub Saharan Africa, climate variability is evident indicated by variability in temperature, shifting rain patterns, sudden rain spells, heat waves, prolonged droughts, and sudden drought spells hitting regions when it is supposed to be a rainy season (McCathy et al., 2008; Ziervogel & Eriksen, 2010; Lobel et al., 2013; Makondo & Thomas, 2020). In the context of East African, changes in climate manifest in the form of decline in the long rainfall season, significant increase in temperatures, and dry seasons crossing into the rain seasons (Nicholson, 2017; Oriangi, 2019). According to IPCC (2001), climate change is the change in the state of climate identified using statistical tests by changes in the mean and/or the variability of its properties persisting for an extended period typically decades or longer while climate variability refers to the variations in the mean state and other statistics such as standard deviation or occurrence of extreme events of climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural processes within the climate system (internal variability) or as a result of variations in natural or anthropogenic external forcing (external variability).

Available outputs from General Circulation Models (GCMs) and Regional Climate Models (RCMs) point to significant climate variability events (Hepworth and Gouden, 2008; Todd et al., 2013). Global and regional weather conditions are expected to become more variable than at present characterized by increased frequency and severity of extreme events such as floods and hail storms, changes in the onset dates of rainfall, and delayed or even failed rains (Ziervogel et al., 2008; Vreiling et al., 2013; Nicholson, 2019; Aturihaihi, 2022). Although more rainfall projections tend to emphasize changes in the annual amount, it is imperative to distil the seasonal changes such as changes in the length of the growing season, and changes in the onset of the rain which may have more significant implications on the productivity of rain-fed agriculture. Studies by (Krishnamurthy & Shuka, 2000; Sultan & Serge, 2000; Barchuk et al., 2005; Gobin, 2011; Todd et al., 2013; Bamba et al., 2020) reported variability in seasonal and intra-seasonal variability of rainfall caused mainly by abrupt shift of the inter-tropical convergence zone. Rowell et al. (1995) noted that global sea surface temperature variations are indeed responsible for most of the variability of seasonal rainfall, the possible effects of land-surface-moisture feedback and the influence of internal atmospheric variations.

Studies indicate that the length of the growing periods (LGP) varies depending on the region and such analysis provides useful information for mapping farming systems (Vreiling et al., 2013). Variability in the LGP is dominant in tropical areas (Vreiling et al., 2013; Kogo et al., 2021). The length of the growing period has been defined variously; Mugalarai et al. (2008) define the length of the growing period as the difference between cessation and onset of a particular year. Additionally, Vrieling et al. (2013) defines the length of the growing period as the period where there are favourable weather conditions for crop emergence, vegetative growth, and ripening. However, this study adopts the definition by Cline (2007) who noted that the length of the growing season is the number of days per year when both water availability and temperature permit crop growth.

More still, the onset of rain is also an important seasonal characteristic that has reflected variability over time (Moron & Robertson, 2013; Omay et al., 2023). Rainy seasons in most cases begin later or earlier than normal (Ziervogel et al., 2008; Zhou et al., 2019). The onset of rains according to Subash et al. (2010) was found to have a significantly delayed trend at a rate of 2.8% of the mean/30 years with an increasing trend in the seasons. Moron and Robertson (2013) noted that the variations in the interquartile range of

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onset of rain vary from less than 2 weeks over the monsoon zone and Western Ghats to about a month over the northwestern desert. These relationships are found to be weak and geographically confined. This study adopts the definition of onset of rain by Camberlin and Diop (2003) who define the onset of rain as the first week receiving at least 15 mm of rainfall after a given date determined by local climatology and agricultural practices provided that no seven days' dry spell occurs in the next 30 days.

In terms of future climates, an analysis done by (IPCC, 2007) projected an increase in global mean surface temperatures by 1.8 ^{o}C by 2050 and by 4.0 ^{o}C by 2100 with tropical regions experiencing the largest increments because of direct exposure of the region to the sun's rays throughout the year. However, McSweeney et al. (2008) reported temperature projections of 1.5 ^{0}C by 2050 and by 4.3 ^{0}C by 2100. Furthermore, ACCRA (2012) projected a rise in temperature by 1.0 ^{0}C to 3.1 ^{0}C by 2060s and 1.4 ^{0}C to 4.9 ^{0}C by 2090s while Alexander (2013) projects even a much higher rise by 4-6 ^{0}C by 2080 which is even above the global increase. These temperature observations indicate variable results and underpin the need to understand historic and projected changes at a local scale.

An evaluation of the projected changes in rainfall is inconclusive and gives mixed results. Many studies indicate an increase ranging between 5% to 40% by 2100 (IPCC, 2007; Schmidhuber & Tubiellos, 2007; Alexander, 2013) while a few studies indicate a decrease on average by 10% to 40% (Some & Kone, 2000; Worishima & Akasaka, 2010). Tropical and high-latitude regions are expected to experience overall increase in precipitation (IPCC, 2007; Druyan, 2010; Sultan, et al., 2013) with the exceptions of a few areas such as southern Africa and parts of the Horn of Africa where rainfall is projected to decline by about 10% by 2050 (Worishima & Akasaka, 2010). Although more rainfall projections tend to emphasize regional changes in annual amounts, it is imperative to distill local historic changes in length of the growing season, changes in the onset, deviations from the long-term annual mean and decadal variations. Studies by Sultan and Serge (2000); Barchuk et al. (2005) and Todd et al. (2013) reported significant seasonal and intra-seasonal variability of rainfall. More still; Ziervogel et al. (2008), and Moron and Robertson (2013) reported that the onset of rain is an important characteristic that has revealed variations over time in most cases beginning later or earlier than normal. It is thus apparent that expected changes in rainfall are spatially constrained; particularly in Africa where a large natural variability exists necessitating more studies which are location specific.

It is clear from the foregoing synthesis that although climate variability and change are generally expected, the expected changes are diverse in terms of magnitude, direction and are geographic specific. The need for information and knowledge on climate variability and change on geographic specific locations thus exists. Therefore, this study established the historic, and future variations and changes in precipitation and temperature in Gulu district in northern Uganda.

MATERIALS AND METHODS

The study was conducted in Gulu District in northern Uganda. Gulu was purposively chosen for being sensitive to climate variability and change (WPF, 2009). It experiences tropical type of climate (wet and dry) (NEMA, 2009). The average annual rainfall is 1500 mm, normally the wet season extends from April to October, while the dry season extends from November to March. Occasionally the area experiences long droughts and irregular rains which are recently becoming more frequent (WFP, 2009).

Historical climatic data was obtained from UNMA consisting of rainfall and temperature data spanning from 1980 to 2010 and 1990 to 2009 respectively. The obtained rainfall and temperature data was on daily, monthly, and annual temporal scales. Future climatic conditions were obtained using the PRECIS model (Providing Regional Climates for Impact Studies). Details of the PRECIS model are widely available

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in Kumar et al. (2008), Yong et al. (2006), Marengo et al. (2009) and Urrutai and Mathias (2009), among others. PRECIS is a Regional Climate Modelling (RCM) system based on the third generation of the UK's Hadley centre's regional climate model. PRECIS downscales climate up to a spatial resolution of 25 km. RCMs represent an effective method of adding fine-scale detail to simulated patterns of climate variability and change as they resolve better the local land-surface properties such as orography, coasts and vegetation and the internal regional climate variability through their better resolution of atmospheric dynamics and processes (Marengo et al., 2009). PRECIS downscaled data for most parts of Uganda are readily available and were obtained from the Meteorology Unit, Department of Geography, Geo-Informatics and Climatic Sciences, Makerere University, which has for a long time worked on climate downscaling in collaboration with University of Reading, ICPAC, and University of Nairobi. The PRECIS model was calibrated using historical climatic data. The obtained PRECIS data was downscaled to a resolution of 50 km. For this study; projections for future climatic conditions were confined to a medium temporal scale (2013- 2033) to obviate the uncertainty associated with long timescale projection.

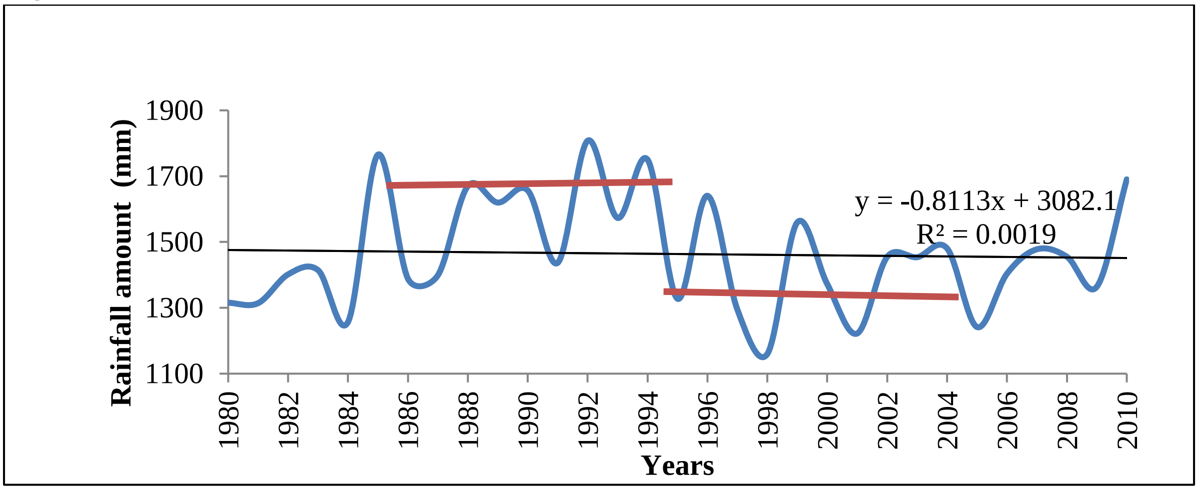
To analyse climate data, the following analytical tools were employed: (a) Regression model to determine the significance of change in historic, current and future rainfall and temperature, (b) Trend analysis to ascertain the patterns and trends of variability and change in rainfall and temperature and it constituted the mean, minimum, maximum, quartiles, standard deviations, coefficients of variation (C.V), percentages, frequencies and the range for the period 1980-2033 for rainfall and the period 1990-2033 for maximum and minimum temperature.

RESULTS

Trends and Patterns in Rainfall

The trend observed in annual rainfall amounts for the period 1980 to 2010 (*Figure 1*), revealed a decreasing trend, the annual rain falls amounts received in Gulu varied from 1160 mm-1808 mm averaging to 1460 mm. A linear trend tilted on the data shows that the decrease is not strong ($R^2 < 0.5$) and is insignificant ($P>0.05$). The annual coefficients of variation (C.V) in rainfall amounts for the period 1980-2010 ranged from 55% to 97% and this implied a high coefficient of variation. Generally, from 1980-1996 oscillations in annual rainfall amounts were above 1300 mm, and from 1997-2010 oscillations were below 1300 mm.

Figure 1: Variations in annual rainfall amount between 1980 and 2010



Deviations in annual rainfall amounts from the long-term mean (LTM) (1460 mm) are illustrated in *Figure 2*. Results revealed that the deviation in annual rainfall amounts from the long-term mean ranged from -300 mm to +348 mm giving a range of 648. A visual inspection of the graph generally

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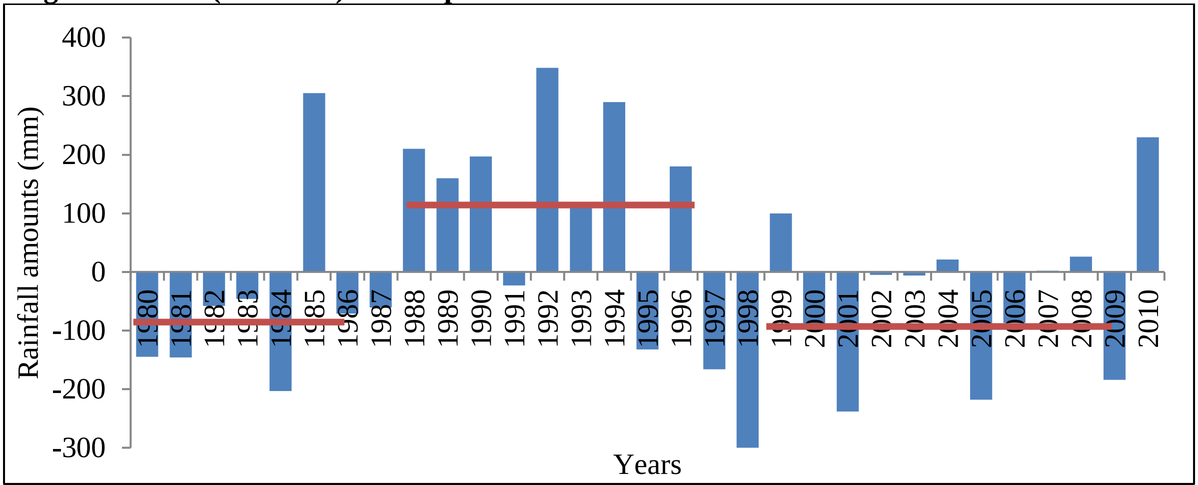
shows that: rainfall amounts for the period 1980-1997 were below the long-term mean, for the period 1988-1996, the annual rainfall amounts were above the long-term mean, and for the period 1997-2009 the annual rainfall amounts were far much below the long-term mean. This implies that rainfall is generally oscillating over time coupled with wide deviations from the long-term mean.

Figure 2: Deviations of annual rainfall amounts in Paicho Sub County in Gulu district from the long-term mean (1460 mm) for the period 1980-2010



Decadal variability in rainfall for the periods 1980-1990, 1991-2000 and 2001-2010 is illustrated in *Figures 3*, *4*, and *5*. Results showed variability of decadal rainfall amounts for the period 1980-2010. For the period 1980-1990 the annual coefficients of variation (C.V) ranged from 19% to 128%; for 1991-2000, the C.V ranged from 15%-189%, and for the period 2001-2010, the C.V ranged from 32%-108%, all these coefficients of variations are considered high variance according to Reed et al. (2000). Decadal variability of rainfall is also revealed by varying minimum, maximum, quartiles and high standard deviations (STDEV). To compare variations in the maximum rainfall received in the three decades, the months of September for example received different amounts of rainfall for the three decades. For the period 1980-1990 it was 327, for 1991-2000 it was 234, and for 2001-2010 it was 282. These results therefore imply high variance in inter-decadal rainfall amounts for Gulu.

Figure 3: Decadal variations in monthly rainfall amounts for Gulu station, 1980-1990

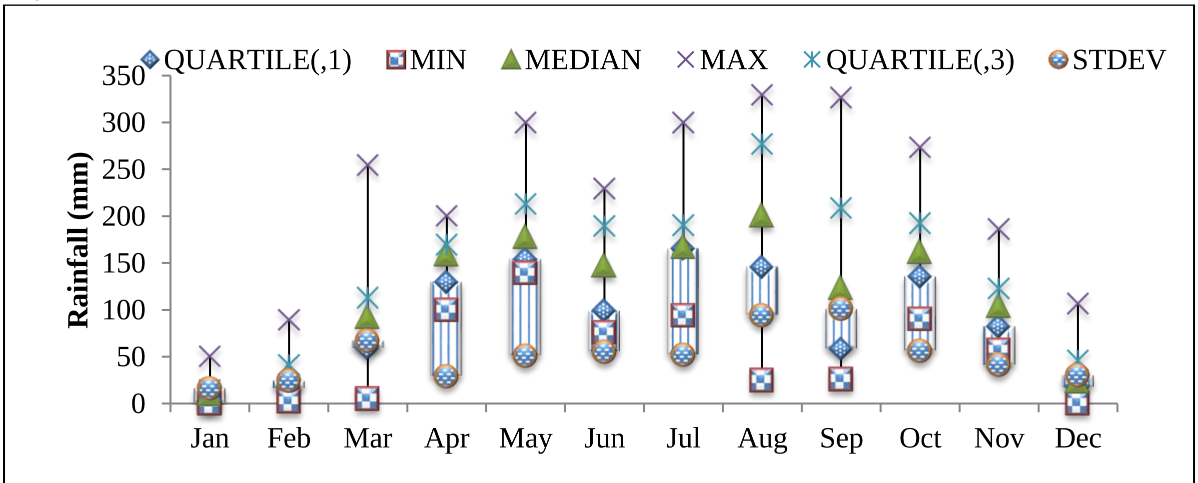


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Figure 4: Decadal variations in monthly rainfall amounts for Gulu station, 1991-2000

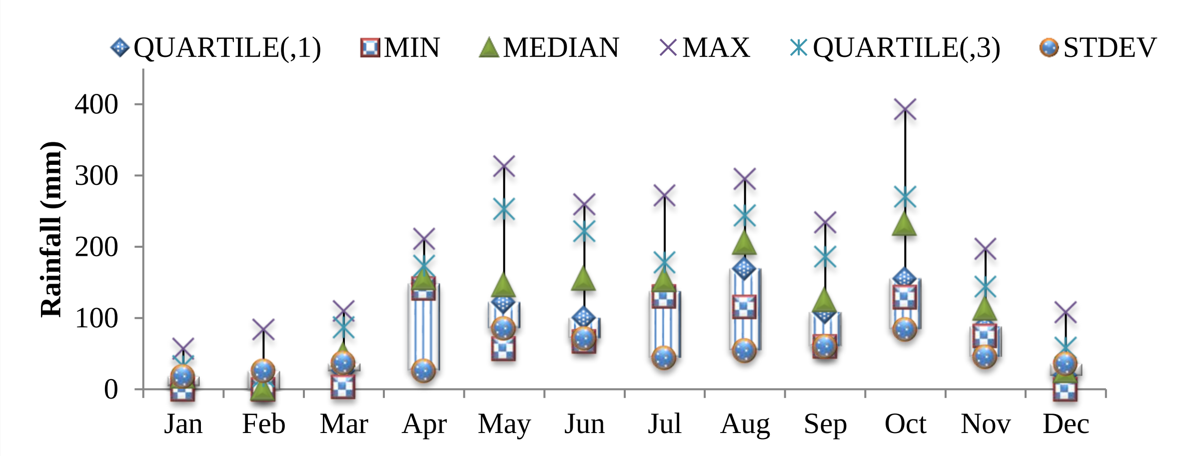
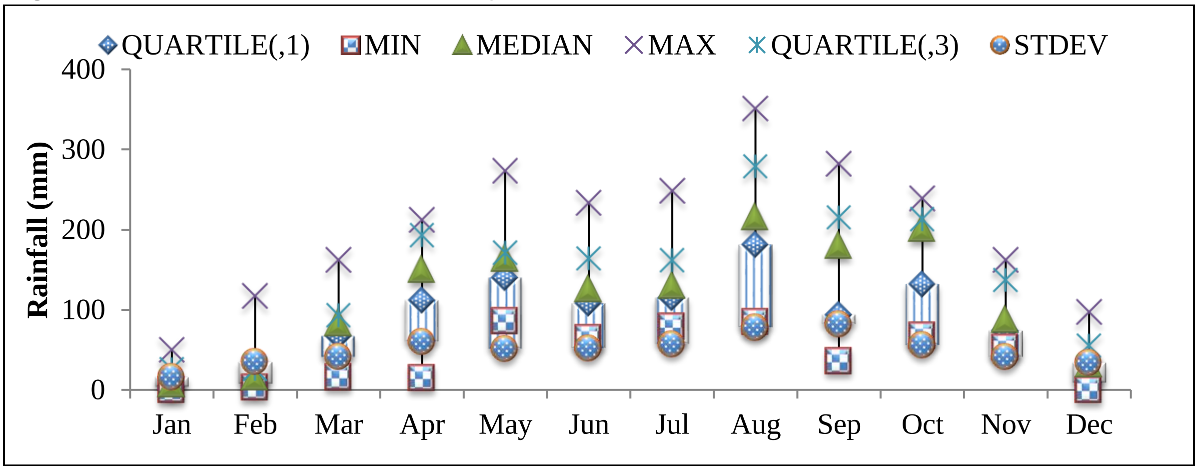
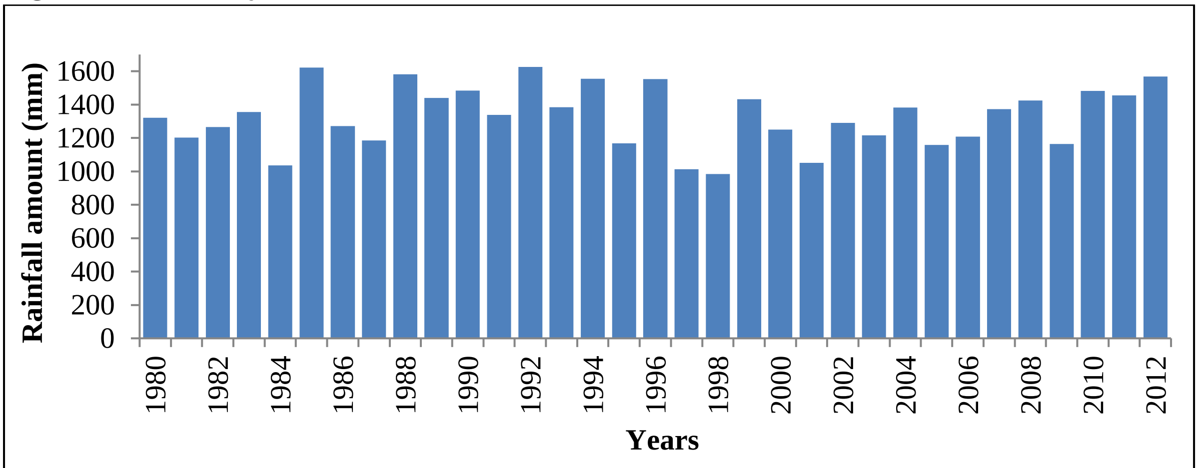


Figure 5: Decadal variations in monthly rainfall amounts for Gulu station, 2001-2010



Variability in seasonal rainfall amounts for the period 1980-2012 is illustrated in *Figure 6*. The area receives one long rainy season that stretches from March to October (WPF, 2009). Results revealed that the seasonal rainfall amounts varied from 985 mm to 1624 mm averaging to 1305 mm, and when subjected to statistical analysis, results revealed that the coefficient of variation in seasonal rainfall ranges from 48%-96%. This implies a high variance in seasonal rainfall amounts.

Figure 6: Variability in seasonal rainfall amounts for Gulu, 1980-2012



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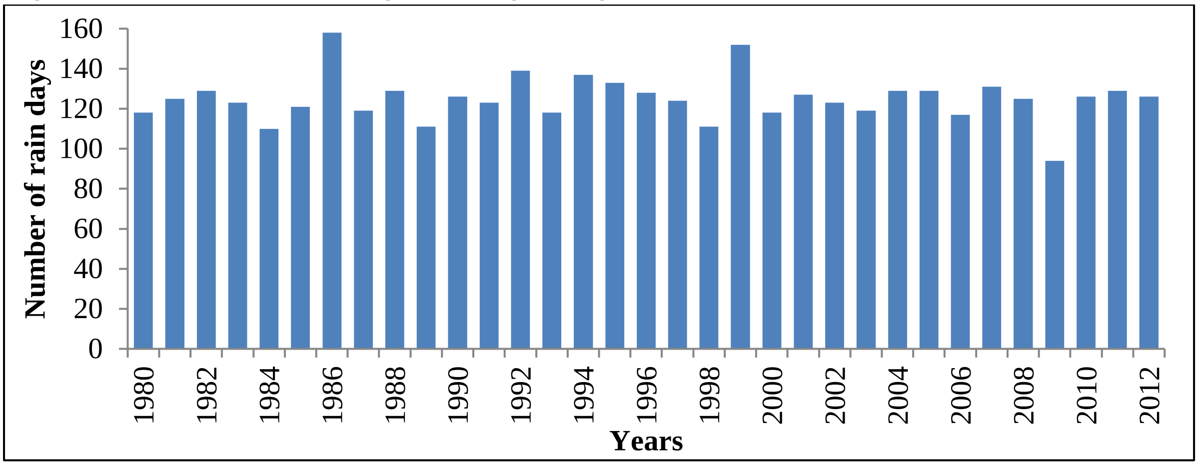
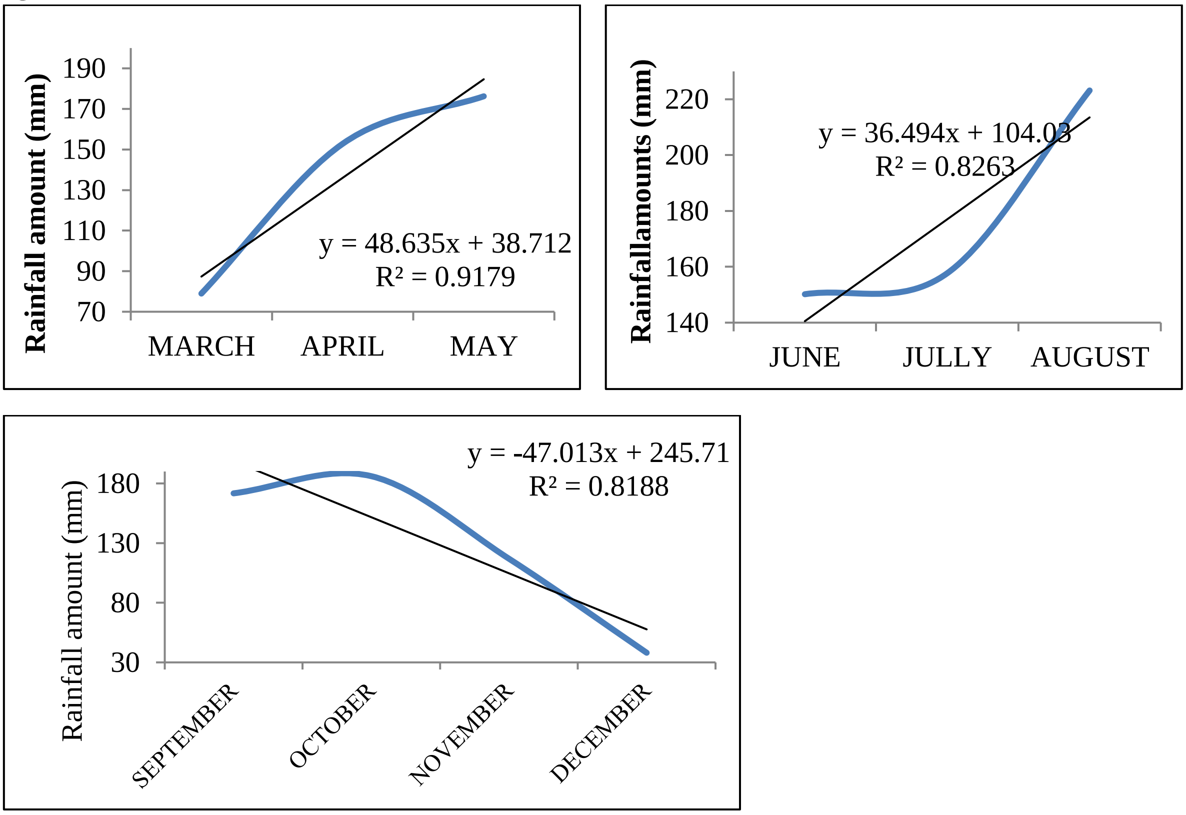
Variation in the length of the growing season for the period 1980-2012 is illustrated in *Figure 7*. Results revealed that the number of rain days during the growing season for the period 1980-2012 ranged from 94 rain days to 158 rain days averaging to 126 rain days. This implies a wide range of variation in the length of the growing season for the period 1980-2012.

Figure 7: Variations in the length of the growing season for the period 1980-2012 in Gulu



Rainfall analysis for March-April-May (MAM), June-July-August (JJA) and September-October-November-December (SOND) is illustrated in *Figure 8*. Results revealed that there was a strong (R^2 >0.5) but insignificant (P > 0.05) increase in rainfall for the months of March-April-May (MAM), a strong (R^2 > 0.5) and insignificant (P > 0.05) increase for the months of June-July and August (JJA), and a strong (R^2 > 0.5) and significant (P < 0.05) decrease in rainfall for the months of September-October- November, and December.

Figure 8: Variation in MAM, JJA and SOND rainfall amounts in Gulu



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Variations in the onset, cessation, and length of growing season for the period 1980-2012 are illustrated in *Table 1*. Findings revealed that the onsets of rain have been varying from 1st. March for the earliest rains to 10th. April for late rain. Statistical analysis shows a high standard deviation of 11. An inspection of the onset dates reveals that in the 1980s, and 1990s, the onset of rain was generally being experienced within the first week, and second week of March but between 2003-2012, the onset of rain has generally been experienced in the third to fifth week of March or even in early April. This implies that the onset of rain has been varying and indicates a shift from early March to late March or early April.

For this study, the end of the rain season was taken to mean the first seven-day dry spell after November first (Tumwesige & Musiitwa, 2001). Findings show variability in the end of rain season indicated by a high standard deviation (13). Furthermore, results revealed variability in the length of the growing season indicated by a high standard deviation (17).

Table 1: The Julian day number of the Start (S), End (E) and Length (L) of the rain season

Year	S	E	L
1980	61	304	243
1981	70	360	290
1982	60	325	265
1983	94	334	240
1984	72	339	267
1985	77	323	246
1986	71	333	262
1987	68	342	274
1988	64	328	264
1989	84	307	223
1990	68	318	250
1991	64	313	249
1992	93	323	230
1993	65	318	253
1994	63	341	278
1995	67	331	264
1996	76	333	257
1997	83	345	262
1998	94	323	229
1999	63	318	255
2000	84	313	229
2001	67	325	258
2002	60	332	272
2003	81	343	262
2004	76	315	239
2005	74	324	250
2006	76	329	253
2007	100	328	228
2008	69	322	253
2009	90	310	220
2010	81	330	249
2011	74	353	279
2012	92	320	228
Minimum	60	304	220
Maximum	100	360	290
Range	40	54	70
Mean	75	328	252
SD	11	13	17

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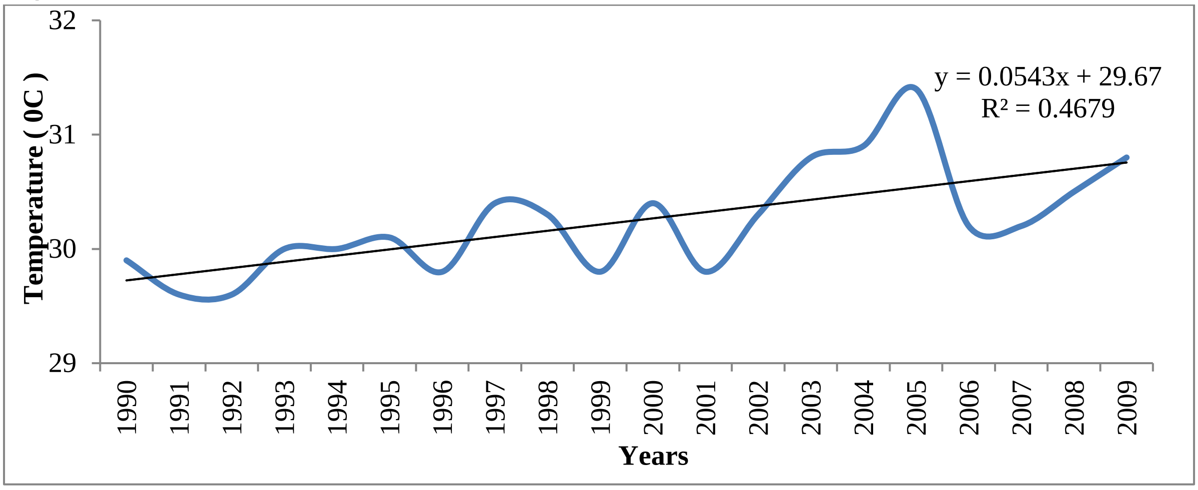
Trends and patterns in temperature

The trend of mean annual maximum temperature for the period 1990-2009 is illustrated in *Figure 11*. The area experienced a linear increase in annual maximum temperatures which was strong (R^2 >0.5) and significant (P < 0.05). It ranged from 27 ^{0}C to 35 ^{0}C averaging to 31 ^{0}C. A visual inspection into the temperature maximum graph revealed that maximum temperatures have been oscillating in an increasing progression indicating increasing trend for the two decades.

Figure 9: Mean annual maximum temperature trend for Gulu, 1990-2009



Decadal variations in mean monthly maximum temperature for the periods 1990-1999 and 2000-2009 are illustrated in *Table 3*. Results revealed that in the period 1990-1999, the coefficients of variation ranged from 2-4% and for the period 2000-2009, the coefficient of variation ranged from 1-4%. This implies high variance in decadal mean monthly maximum temperature.

Table 2: Decadal maximum temperature variations for the periods 1990-1999, and 2000-2010

Temperature Maximum	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1990-1999						
Quartile (1)	31	32	32	30	29	28	28	28	29	29	29	30
Min	30	31	31	29	28	27	27	27	29	28	28	29
Median	32	33	32	30	29	29	28	28	29	29	29	31
Max	33	35	35	31	30	30	30	29	32	30	30	32
Quartile (3)	33	33	34	31	29	29	28	29	30	29	30	31
Stdev.	1	1	1	1	1	1	1	1	1	1	1	1
C.V	4	3	4	3	2	2	3	2	4	2	3	4
						2000-2009						
Quartile (1)	32	33	32	30	29	29	28	28	29	29	30	31
Min	31	33	31	30	29	28	28	28	28	28	29	29
Median	32	34	33	31	30	29	29	29	29	30	30	31
Max	33	35	34	32	30	30	30	29	30	31	32	34
Quartile (3)	33	34	33	31	30	30	29	29	30	30	30	32
Stdev	1	1	1	1	0	1	1	1	1	1	1	1
C.V	2	3	3	2	1	2	3	2	2	3	3	4

C.V is Coefficient of variation, STD is Standard deviation, MIN is Minimum, MAX is Maximum

The trend of mean annual minimum temperature for the period 1990-2009 is illustrated in *Figure 10*. The minimum temperature also increased linearly with time. It varied from 17 ^{0}C to 21 ^{0}C averaging to 19 ^{0}C, and statistical analysis revealed that the increase was statistically strong (R^2 > 0.5), and significant (P < 0.05). A visual inspection into the temperature minimum graph for the period 1990-2009 revealed that minimum temperatures have been varying in an increasing

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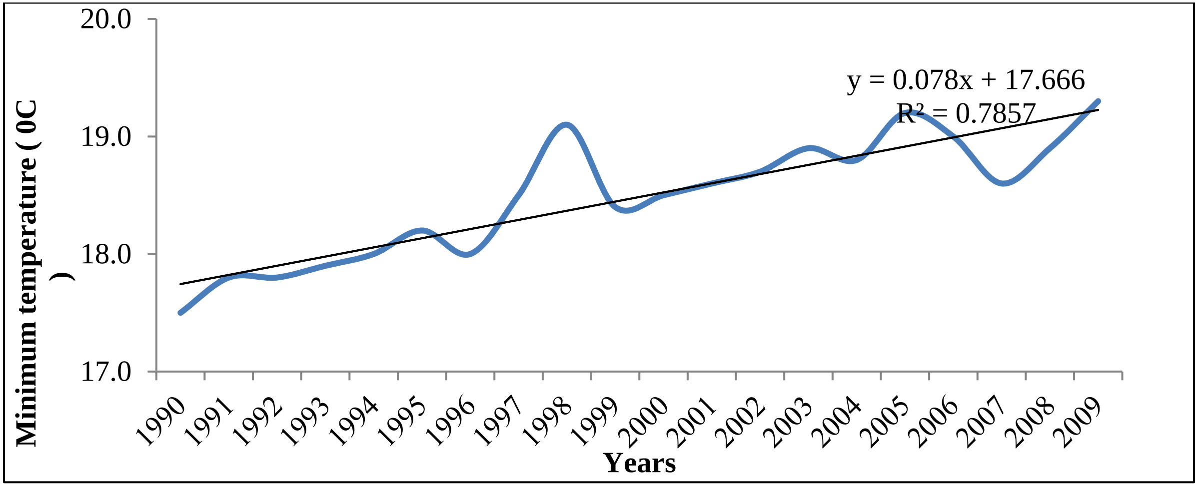
progression indicating increasing regime for the two decades.

Figure 10: Mean annual minimum temperature trend for Gulu, 1990-2009



Decadal mean monthly minimum temperature in the period 1990-1999 is illustrated in *Table 3*. Findings revealed that the coefficients of variation ranged from 2-4% and for the period 2000-2009, the coefficient of variation ranged from 1-5%. This implies high variance in decadal mean monthly minimum temperatures.

Table 3: Decadal variations in minimum temperature for the periods 1990-1999 and 2000-2009

Temperature minimum	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
						1990-1999						
Quartile (1)	17	18	19	19	18	18	18	17	17	18	17	17
Min	17	18	18	18	18	18	17	17	17	17	17	17
Median	17	18	19	19	18	18	18	18	18	18	18	17
Max	19	20	21	20	20	19	19	19	19	19	19	18
Quartile (3)	18	19	20	19	19	19	18	18	18	18	18	18
Stdev	1	1	1	1	1	0	0	0	1	1	1	0
C.V	3	4	4	3	3	2	2	3	3	3	3	2
						2000-2009						
Quartile (1)	18	19	19	19	19	19	18	18	18	18	18	18
Min	18	18	18	19	19	18	18	18	18	18	18	18
Median	19	20	20	19	19	19	18	18	18	19	19	19
Max	19	21	21	20	20	19	19	19	19	19	19	19
Quartile (3)	19	20	20	20	19	19	19	18	18	19	19	19
Stdev	1	1	1	0	0	0	0	0	0	0	0	0
C.V	3	5	3	2	1	1	2	1	2	2	2	2

Projected Changes in Rainfall

The trends observed in projected annual rainfall amounts for the period 2013-2033 are illustrated in *Figure 11*. Projected annual rainfall amounts are likely to have a significant decrease ($P > 0.05$) for the period 2013-2033. This implies that changes in rainfall are likely to occur in Gulu by 2033.

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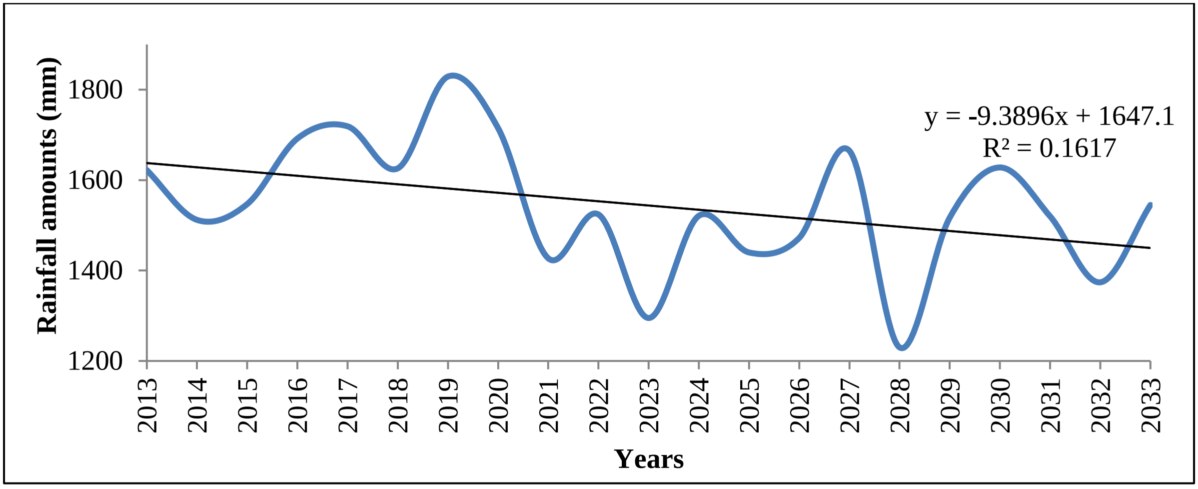
Figure 11: Projected trend of rainfall for Gulu, 2013-2033



Projected Changes in Maximum and Minimum Temperature

The projected mean annual maximum and minimum temperature for the period 2013-2033 is illustrated in *Figure 12* and *13*. The trends observed in mean annual maximum and minimum temperature is likely to remain quasi uniform ($R^2 < 0.5$), and ($P> 0.05$) for the period 2013- 2033. This implies that mean annual minimum and maximum temperature for Gulu is likely to vary rather than change by 2033 characterized by slight oscillations.

Figure 12: Maximum temperature

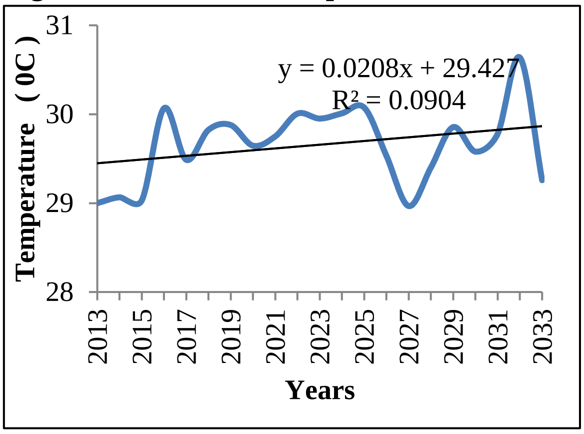
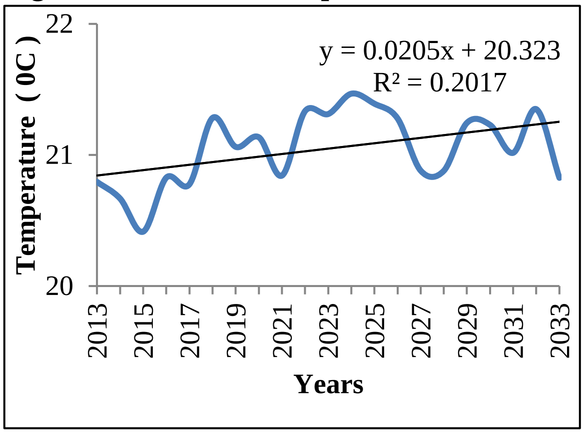


Figure 13: Minimum temperature



DISCUSSION OF RESULTS

Variability in Rainfall

The trend observed in annual rainfall amounts for Gulu is decreasing for the period 1980-2010. A linear trend tilted on the data shows that the decrease was insignificant but depicted a high coefficient of variation implying that the area is currently contending more with rainfall variability rather than change and this was supported by household perceptions. This is contrary to perceived wisdom and evidence from most empirical studies (Cynthia, 2002; IPCC, 2007; Schmidhuber & Tubiellos, 2007; Alexander, 2013). However, Some and Kone (2000) reported that in the semi-arid and sub humid zones of West Africa, rain fall is decreasing. Similarly, Worishima and Akasaka (2010) reported that rainfall in southern Africa and parts of the Horn of Africa is decreasing and these are in line with the findings from this study.

Furthermore, the study found out deviations of annual rainfall amounts from the long term annual average ranging from -300 to +348 mm for the period 1980-2010. Generally, the deviation was below the long-term average for the period 1980-

1987, above the long-term average for the period 1988-1996, and far much below the long-term average for the period 1997-2009. The causes of deviation of annual rainfall from the long-term annual average in Gulu is likely to be a result of: early onset, followed by a delay in cessation, and increased intensity of seasonal rainfall which can cause an increase in annual rainfall amounts above the long term average while dry spells, prolonged droughts, delayed onset followed by early cessation, and reduced intensity of seasonal rainfall can cause a decrease in annual rainfall amounts below the long term average. The deviation of annual rainfall amounts in Gulu is coupled with decadal variations in rainfall amounts, and statistical data analysed revealed high variance in inter-decadal rainfall amounts for decades 1980-1990, 1991-2000, and 2001-2010.

In terms of seasonality, Gulu receives one long rainy season that stretches from March to October. The seasonal rainfall amounts for the period 1980-2012 varied from 985 mm to 1624 mm averaging to 1305 mm, and this depicted a wide variation. Statistical analysis revealed a high coefficient of variation in seasonal rainfall amounts for the area. Similarly, studies by Krishnamurthy and Shuka (2000); Sultan and Serge (2000); Barchuk et al. (2005); Gobin (2011), and Todd et al. (2013) found out variability in seasonal rainfall amount in the tropics mainly caused by abrupt shift of the inter-tropical convergence zone. Rowel et al. (2007) reported that global Sea Surface Temperature (SST) variations, the possible effects of land-surface-moisture feedback, and the influence of internal atmospheric variations are indeed responsible for most of the variability of seasonal rainfall. These are likely to be the probable causes of seasonal variability of rainfall amounts in Gulu.

Investigation on the onset dates, cessation dates, and the length of the growing season (LGS) revealed the following: the onset of rain has been varying, and indicated a shift from early March to late March or early April. This finding relates to the findings of Ziervogel et al. (2008), and Morons and Robertson (2013) who found out that the onset of rainfall in most cases begin later or earlier than normal.

The findings for the end of the rains, and length of the growing season revealed a high variability indicated by a high standard deviation of 13, and 17 respectively. Similarly, Vreiling et al. (2013) reported variability in the length of the growing season in arid, and semi-arid areas, significant negative trends in Tanzania, Mozambique, and for short rains in Eastern Kenya. Similar findings on variations in LGS have been observed when climatological growing season was studied for large parts of the northern hemisphere (Frich et al., 2002). Linderholm (2006), and ACIA (2004) assert that variations that occur in the LGS are associated with global warming.

Rainfall analysis for March-April-May (MAM), June-July-August (JJA), and September-October-November-December (SOND) revealed that there was a strong but insignificant increase in rainfall for the months of March-April-May (MAM), a strong, and insignificant increase for the months of June-July, and August (JJA), and a strong, and significant decrease in rainfall for the months of September-October- November, and December.

Variability in Temperature

Mean annual maximum, and minimum temperature for Gulu for the period 1990-2009 were linearly increasing though at different rates. This statistical finding was supported by household perceptions that air temperature is one of the climatic parameters that have varied most. This is in line with the assertion that annual temperatures are generally increasing in the region (Schmidhuber & Tubiello, 2007; NRC, 2001; ACCRA, 2012). The causes of increasing minimum, and maximum temperatures in different regions in most cases are not location specific but derived mostly by the interconnected effect of global human activities, and natural factors. A study by Makokha and Shisanya (2010) in Nairobi, Kenya reported increasing maximum, and minimum temperature due to air pollution resulting from increasing energy consumption, and alteration of the natural landscape by human

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activities. Adger and Brown (1994) reported the effect of land use change resulting from deforestation, agriculture, and urbanization to be a cause of increasing temperature. Nantalia et al. (2000), and Crowley (2000) asserted that global temperature changes are caused by 'external' factors of anthropogenic activities, volcanoes, variations in the irradiance of the sun, and the 'internal' factor of natural variability.

High variances in the inter-decadal, and intra-decadal temperature were also observed for the period 1990-1999, and 2000-2009. Similarly, there have been variations in the highest decadal mean monthly maximum temperatures for the 2 decades with the highest temperatures of between 30 ^{0}C to 35 ^{0}C registered during the dry months of January, February, and December, and the lowest mean monthly maximum temperatures registered during the rainy seasons ranging from March to November. This finding is related to the finding of Nandozi et al. (2012) in Uganda, and that of Subas (2012) in India who report large seasonal changes in environmental temperatures. It is also in line with findings by Schmidhuber and Tubiello (2007), and IPCC (2007) who assert an increase in global atmospheric temperature.

Projected Changes in Rainfall

The trends in projected annual rainfall amounts for Gulu was found to be decreasing for the period 2013-2033, and statistical analysis revealed that the decrease is statistically significant. The study finding relates to the findings of Nandozi et al. (2012), Worishima and Akasaka (2010) who reported that rainfall in South Africa and parts of the Horn of Africa is projected to decline by 10% by 2050. Similarly, Some and Kone, (2000) reported that rainfall in the semi-arid, and sub humid zones of West Africa was decreasing. However, this finding deviates from the general notion that rainfall in the coming decades is likely to increase (NRC, 2001; Cynthia et al., 2002; Schmidhuber & Tubiellos, 2007; Alexander, 2013). A study by IPCC (2007) reported that the intensity of precipitation events is likely to increase on average and this will be particularly pronounced in tropical and high-latitude regions which are also expected to experience overall increase in precipitation because of high evapotranspiration. Mohamed et al. (2002); Druyan, (2010), and Sultan et al. (2013) also reported that rainfall is projected to increase over the African continent. ACCRA (2012), and Bashaasha et al. (2010) reported that the increases in rainfall in Uganda are largest in short rain season with heavy rainfall events. Although climate change is generally expected, the expected changes are diverse in terms of magnitude, direction, and are geographic specific.

Projected Changes in Maximum, and Minimum Temperature

The trends in both projected mean annual maximum, and minimum temperature for Gulu for the period 2013-2033 shows an increasing trend, and statistical analysis revealed that the increase is statistically insignificant. This implies that mean annual maximum, and minimum temperature will vary rather than change by 2033 for Gulu. This agrees with the notion that mean surface temperature will increase (Xiaodong et al., 2006; IPCC, 2007; Schmidhuber & Tubiello, 2007; NRC, 2001; ACCRA, 2012). However, variations exist in the magnitude and the temporal extent of predictions. IPCC (2007) projects an increase in mean surface temperature between 1.8 ^{o}C to 4.0 ^{o}C by 2100 with tropical regions experiencing the largest increments likely because of prolonged droughts, dry spells, and direct exposure of the region to the sun's rays throughout the year. McSweeney et al. (2008) reported temperature increase of 1.5 ^{0}C by 2050, and of 4.3 ^{0}C by 2100 in Uganda. ACCRA (2012) reported a rise in temperature from 1.0^{0} to 3.1 ^{0}C by 2060s, and 1.4 ^{0}C to 4.9 ^{0}C by 2090s still in Uganda while Alexander (2013) projects even a much higher rise by 4-6 ^{0}C by 2080 in Mekong region in Asia which is even above the global increase. All projections indicate increase in the frequency of hot days and nights, and a decrease in the frequency of days, and nights that are considered 'cold' in current climate (ACCRA, 2012; Wasige, 2009).

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CONCLUSIONS

Rainfall variations are insignificant for the period 1980-2010, but temperature shows significant variations. This implies that the country needs to continue embracing international policies on climate change mitigation, and adaptation so us to avert elevated eventualities in the future. There is a shift in rainfall onset from early March to late March, and early April. This has a practical implication on farmers to shift their planting time since Uganda's agriculture is largely rain fed. Furthermore, there is a likelihood of an elevated multiplication of agricultural pests, and diseases thus, agronomists need to come up with crop, and animal varieties that are adopted to rising temperatures.

Future projections show significant decrease in rainfall, and insignificant increase in temperature. Thus, agricultural policies need to put more efforts in popularizing irrigation systems to support cropping systems under reduced rainfall. Additionally, projected decrease in rainfall and temperatures by 2033 is likely to affect households therefore, households need to enhance water harvesting techniques to reduce water shortages under reduced rainfall, and also enhance crop production. The study determined variations and changes in climate over a medium time scale therefore, further long-term investigations to determine the likely changes that would occur in climate in the region is still necessary.

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