Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 15 Issue 4 Version 1.0 Year 2015
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

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*Keywords:* *rainfall variability, rainfall trends, farmers' perceptions, eastern uganda.*

*GJSFR-H Classification :* *FOR Code: 300899*

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# Characterization of Historical Seasonal and Annual Rainfall and Temperature Trends in Selected Climatological Homogenous Rainfall Zones of Uganda

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*Keywords: rainfall variability, rainfall trends, farmers' perceptions, eastern uganda.*

## I. Introduction

The weather is an important part of the natural environment (Gomez-Martin, 2005), which affects in various ways many of human activities (Trenberth *et al.*, 2000; Tuckera and Gilliland, 2007). Agriculture is one of the most climate sensitive sectors globally (IPCC, 2001; United Nations, 2009). In many parts of the world including Uganda, agriculture is mainly rain-fed; hence failure of rains can lead to crop failures, food insecurity, famine, mass migration, and negative national economic growth (Stampone *et al.*, 2011). In Uganda, agricultural still remains one of the major economic sectors contributing more than 20% of Uganda' GDP and employing over 80% of the population and is the main means of subsistence of most small holder farmers (Mukiibi, 2001; AGRA, 2010; MAAIF, 2011).

Uganda is endowed by a variety of climatic conditions despite lying within a relatively humid equatorial climate zone due to geographic features such as topography, prevailing winds, lakes, and rivers cause local variations in annual precipitation and temperature, leading to large differences and a relatively complex pattern of annual rainfall (Byakola 2007). Rain falls during two seasons in the south and one season in the north and eastward Chetri *et al.* 2004). This is linked to the seasonal migration of primary humid air masses and convergence zones over Africa that shift towards a northerly location in August and to the south in January. The country is divided into 16 climatologically homogenous zones (Basalirwa, 1995). This information has been usefully applied for planning purposes, and particularly in the agricultural sector. Recent analyses have demonstrated that certain climatic parameters in selected zones have significantly changed with time (Nimusiima *et al.*, 2013). These changes have seriously affected planning and management of subsistence and cash crops in those zones (Phillips and McIntyre, 2000; Fischer *et al.*, 2005). Limited studies have tried to analyze at a fine-scale climatic trends in East African sub-regions and Uganda in particular (Phillips and McIntyre, 2000; Thornton *et al.*, 2009). This is due to lack of complete long-term datasets covering all the regions, existence of complex environmental conditions induced by the topography, proximity to large inland water bodies, and the existence of large tracts of forest

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(Myers, 1991; Indeje *et al.*, 2000). This study evaluates trends in rainfall and temperature (Tmax and Tmin respectively) for all climatologically homogenous zones of Uganda to assist small holder farmers and land use managers in developing effective adaptive management.

## II. Materials and Methods

*a) Description of major homogeneous climatic zones*

Uganda lies in East Africa, astride the equator with its area lying between latitude 4012'N and 1029'S and longitude 29034'W and 3500'E (Ojakol, 2001). The country occupies 241,551 square kilometres of largely fertile arable land. It is bordered to the east by Kenya, to the north by South Sudan, to the west by the Democratic Republic of Congo, and to the south by Rwanda and Tanzania. The country is located on a plateau, averaging about 1100 meters above sea level sloping down to the Sudanese Plain to the north. Large parts of the country have fertile soil with regular rainfall and agriculture is the mainstay of both the national economy and the main source of livelihood for most Ugandans. Subsistence farming is the main source of household income for the majority of Ugandans. The country is divided into 16 Homogenous climatological zones (Figure 1) (Basalirwa, 1995) which are described in Table 1.

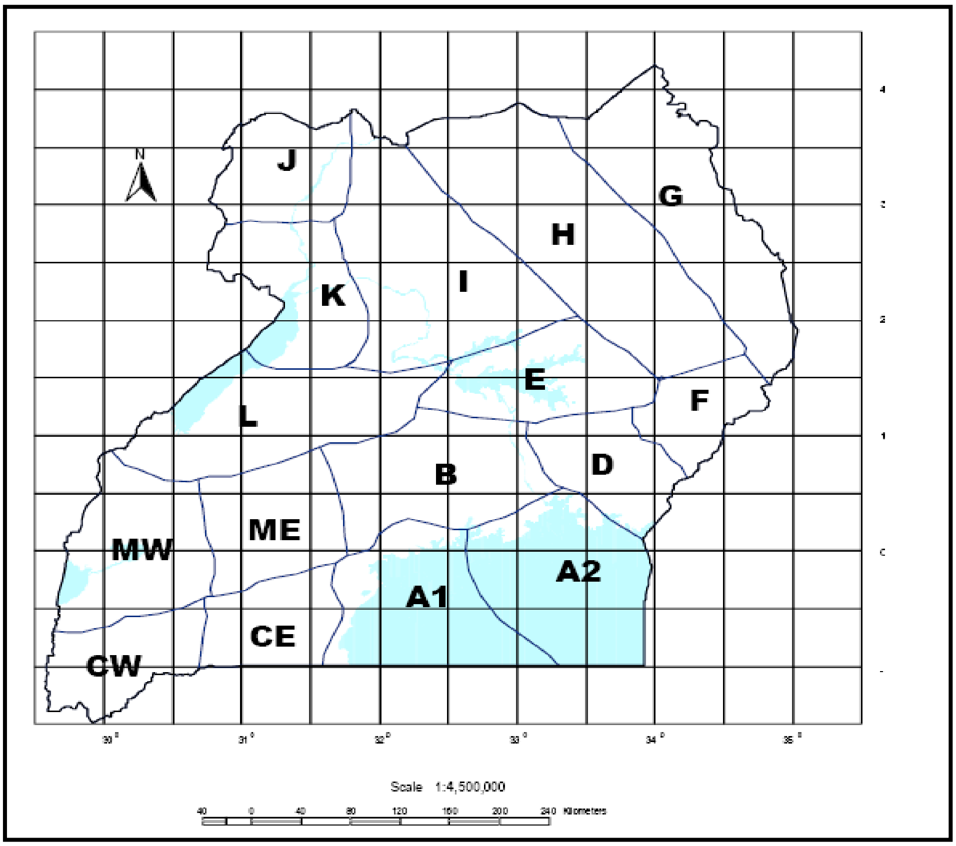



*Figure 1 :* Climatologically Homogenous rainfall zones of Uganda (Basalirwa, 1995)

*Table 1 :* Description of the climatologically homogenous rainfall zones of Uganda

| Climatologically homogenous rainfall zones | Representative station | Annual Rainfall and its zonal variability |
|---|---|---|
| A1 | Entebbe | Western Shores of L. Victoria and Western Masaka. Two rainy seasons, main season March to May with peak in April and secondary season October to December with a peak in November |
| A2 | Jinja | Average rainfall range of 1215 mm - 1328 mm, two rainy seasons in the southern part with the main season from March to May with peak in April and secondary season from August to November with a peak in October/November. |
| D | Tororo | Average rainfall range of 1215 mm - 1328 mm, two rainy seasons in the southern part with the main season from March to May with peak |

| | | |
|---|---|---|
| | | in April and secondary season from August to November with a peak in October/November. |
| ME | Mbarara | Average of 1223 mm. High variability, lowest-800 mm. |
| *L* | *Masindi* | Average of 1270 mm, STD 135mm. High variability, from-800 over Eastern Lake Albert parts to-1400mm over the western parts. |
| E | Soroti | Annual rainfall average of 1250 mm, with two rainy seasons. The main season occurring in March to May with the peak in April, November with a moderate peak in October/November. |
| F | Mbale | Average rainfall range of 1215 mm - 1328 mm, two rainy seasons in the southern part with the main season from March to May with peak in April and secondary season from August to November with a peak in October/November. |
| H | Kitgum | Average of 1197 mm, STD 169 mm, Moderate variability, 1000 over-due north and northeastern parts to -1300mm over the southern parts. One rainy season of about 7 months, April to late October with a main peak in July/August and secondary peak in May. |
| I | Gulu | Average of 1340 mm, STD 155 mm, moderate variability from- 1200 over northwestern and western parts to- 1500 mm over the southern parts |
| J | Arua | Average of 1371 mm, STD = 185mm. Moderate variability, from 1200 over the eastern parts and higher-1500 mm over the western parts |
| K | Nebbi | Average 1259 mm, STD= 195 mm. High variability from-800 within the Lake Albert-1500mm over the western part. Mainly one rainy season of about 8 months, late March to late November with the main peak. August to October and a secondary peak in April/May. |
| MW | Kasese | Kasese rift valley, highest overslopes of Rwenzori Mountains, over 1500 mm. |

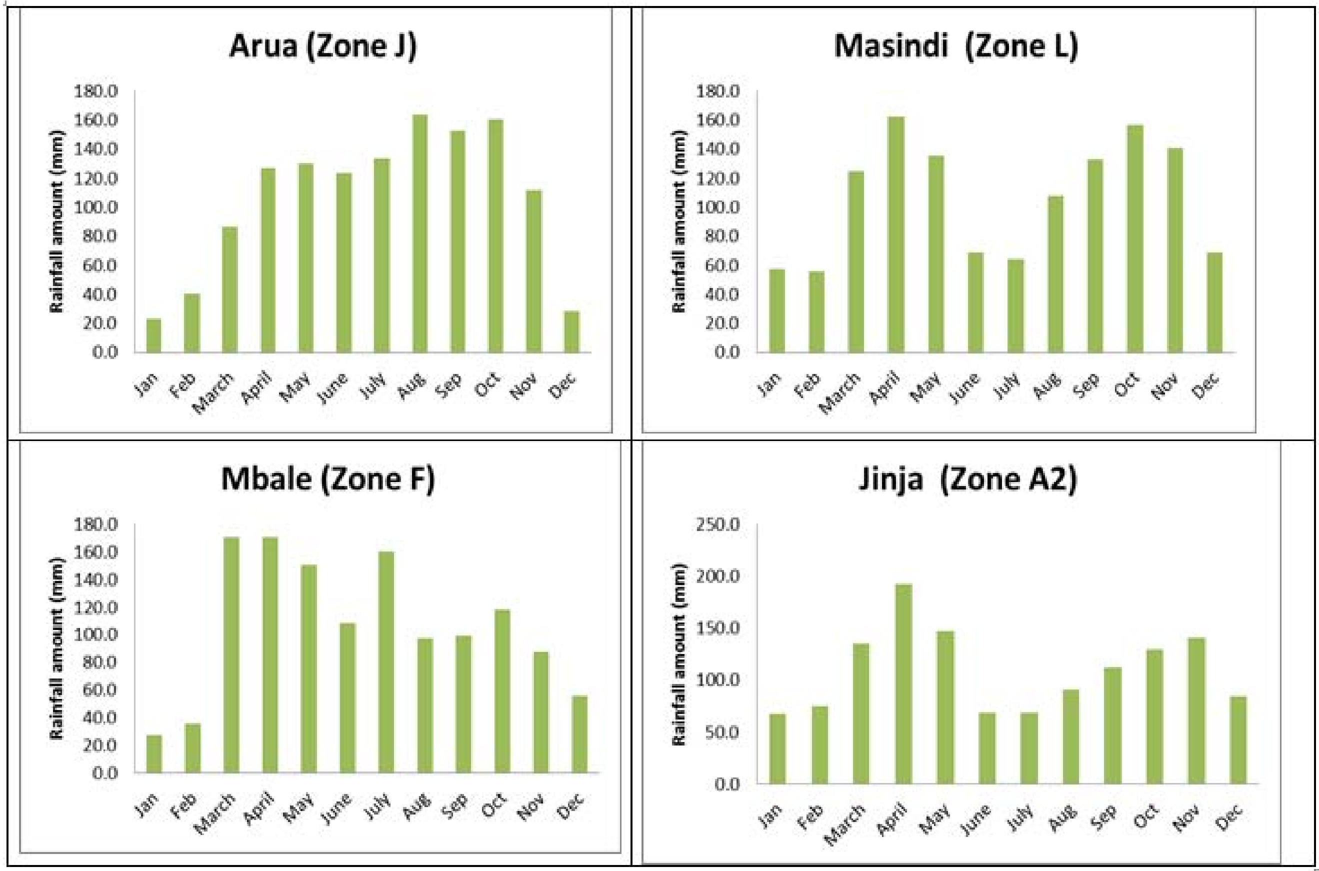
*b) Characterization of the historical climatic trends*

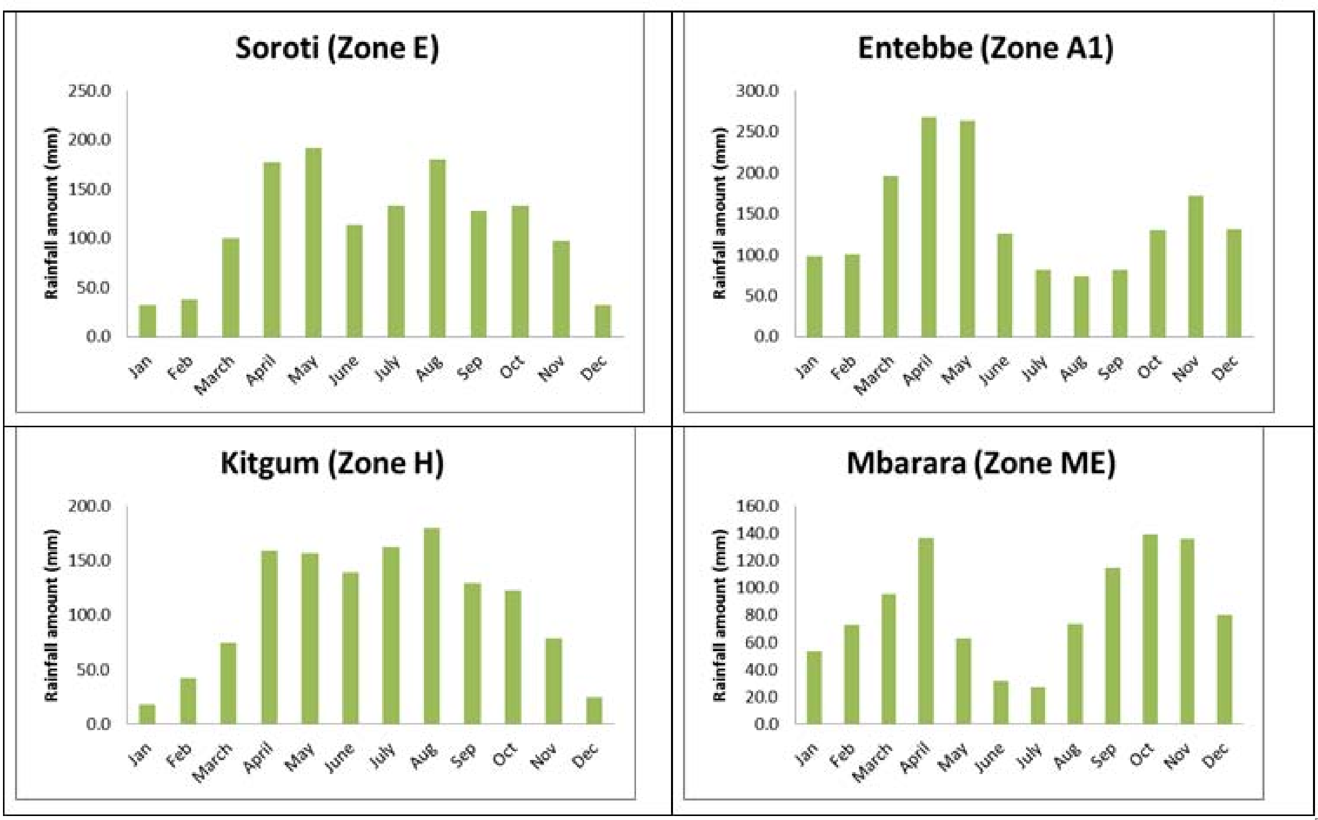
To characterize the historical climatic trends, a representative station was identified in each of the 16 climatologically homogenous zones based on availability of data for rainfall and temperature (maximum and minimum) at Uganda Meteorological Department. Stations with a maximum 15% data gap for the studied period were considered adequate for the study. Most of the stations had monthly data for a period of 1970 to 2005, but the analysis conducted in this study only covered the 1970 to 2000 period. In addition, Long-term climate data (1980-2010) was obtained from the NASA's climate data repository Modern Era-Retrospective Analysis for Research and Applications (AgMERRA) (Rienecker *et al.*, 2011; Ruane *et al.*, 2014) for the stations considered in the study. MERRA data are produce using their 4-Dimensional Variational (4D-Var) assimilation system and were provided in AgMIP extension (Ruane and Goldberg, in preparation). AgMERRA data were used to fill temperature gaps for the stations presenting gaps and were adjusted to fill gaps in rainfall for stations without rainfall data for the period 1980 to 2000 (Ruane et al., 2015). The percentage of gap filled varied from one station to another, but it ranged from 2 to 14% for the studied stations. Station records were evaluated for discontinuities by inspection of each time series and station then tested for homogeneity using the Student's t-test and the Mann-Whitney test (von Storch and Zwiers, 1999; Stampone *et al.*, 2010) before subjecting the dataset to trend and variability analysis using regression techniques, autocorrelation and coefficient of variation for monthly, seasonal and annual values; respectively using Genstat version 13$^{th}$ Edition.

## III. Results and Discussion

*a) Monthly rainfall patterns*

The monthly rainfall patterns of the selected rainfall climatological zones are shown in Figure 2. Rainfall showed a bimodal pattern for all the rainfall zones with clear seasons for L, A2, ME, MW and D; while the zones K, H, F, I, and E had rainfall amount above 50 mm for at least nine months in a year. All these zones had their first peak in April. The second peak was observed in October for L and ME. The rainfall zone A1 had peak rainfall amount for the month of April and May. A2 and A1 zones had their second peak in November and of relatively lower rainfall amount than first peak. The second peak of the rainfall zones ME and D was in October-November. The rainfall zones J, H, F, I and E tended to have a peak in August, except zone F which had a prolonged peak in the months of March to July. Months with minimum rainfall amount varied from one rainfall zone to another. The zones L and A1 had lowest rainfall values in the months of January, February, June, July and December. The rainfall zone A1 had its monthly lowest values in January, February, July, August and September. The rainfall zone D had January, July and December as month with lowest rainfall amount; while ME had June and July as months with lowest rainfall amount. Apart from the rainfall zone E and F which had lowest rainfall amount in December to February and January to February; respectively, all the remaining rainfall zones had their minimum rainfall amount in December to January.



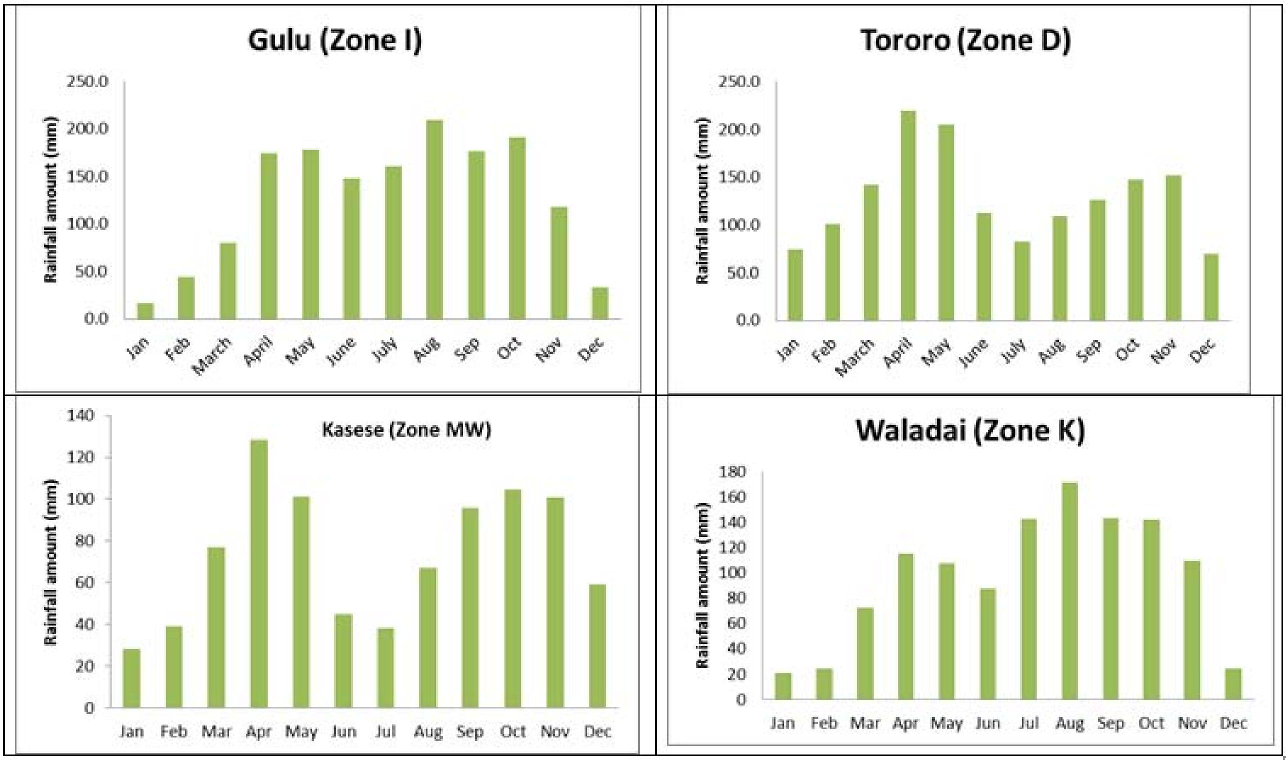



*Figure 2 :* Monthly rainfall distribution in selected climatological rainfall zones of Uganda (Average of 30 years: 1970-2000)

*b) Seasonal rainfall*

Seasonal MAM and SON average rainfall amount, maximum and minimum, standard deviation and coefficient of variation are shown in Table 2 for all the studied zones. The average rainfall amount varied between 237 mm (MW) and 536.8mm (F) for MAM and 426.9 mm (MW) and 837.5 mm (L) for SON. A relatively lowest MAM maximum rainfall amount (428 mm) was recorded in Zone ME and the highest (864.2 mm) in zone F. Zone MW recorded the relatively lowest minimum (88.4 mm) and zone A2 the relatively highest rainfall amount (349 mm) for MAM. The relatively lowest SON maximum rainfall amount (837.5 mm) was recorded in zone L and the lowest (426.9) in zone MW. The minimum amount of rainfall under SON was observed under zone D (83.1 mm) and the highest (346 mm) under L. The standard deviation varied between 66.1 mm (J) and 148.4 mm (F) for MAM and 71.7 mm (F) and 155.9 mm (D) for SON. The coefficient of variation (CV) varied between 15.6 % (A2) and 34.7% (D) for MAM and 17.8 % (J) and 42.8% (D).

*Table 2 :* Summary statistics of MAM and SON rainfall amount in the selected zones

| Zones | MAM | | | | SON | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean (30 years) | Max (Min) | σ | CV | Mean (30 years) | Max (Min) | σ | CV |
| E | 472.8 | 753 (317.6) | 121.9 | 25.8 | 358.0 | 463.8 (216.3) | 76.8 | 21.5 |
| A2 | 491.8 | 632 (349) | 77.1 | 15.6 | 408.3 | 527.6 (227) | 79.8 | 19.5 |
| D | 372.8 | 636.6 (137.9) | 129.4 | 34.7 | 364.2 | 780.3 (83.1) | 155.9 | 42.8 |
| F | 536.8 | 864.2 (233) | 148.4 | 27.6 | 316.3 | 481.2 (209.9) | 71.7 | 22.6 |
| L | 464.8 | 731 (313) | 94.8 | 20.4 | 560.5 | 837.5 (346) | 136.8 | 24.4 |
| J | 260.7 | 400 (140.5) | 66.1 | 25.4 | 459.8 | 626.3 (225) | 81.9 | 17.8 |
| MW | 237.0 | 460.5 (88.4) | 81.7 | 34.4 | 274.4 | 426.9 (141.8) | 80.7 | 29.4 |
| ME | 292.9 | 428 (146) | 69.8 | 23.8 | 384.1 | 596.2 (207) | 92.8 | 24.2 |
| H | 402.4 | 705.4 (286) | 88.8 | 22.07 | 334.9 | 531 (167.6) | 95.0 | 28.4 |
| I | 433.0 | 708.8 (242.3) | 93.7 | 21.6 | 483.8 | 803.3 (275.5) | 139.0 | 28.7 |
| K | 295.4 | 516 (137.9) | 85.1 | 28.8 | 394.9 | 552(216) | 83.5 | 21.1 |
| A1 | 679.6 | 1123.6 (322) | 200.5 | 29.5 | 359.9 | 605.3 (182.5) | 110.0 | 30.6 |

Seasonal rainfall trends varied from one climatological homogenous rainfall zone to another and season. Three categories of trends were observed on the selected and studied zones. These included zones without any significant seasonal trend, zones with only one season showing a significant trend, and zones for which both seasons varied significantly with time. Zone ME and H (Figure 3) are in the first category; seasonal rainfall amount were undulating without significant pattern (P>0.05). The Pearson correlation between year and rainfall was also very low and not significant for both season in the two zones and were of 0.09 for SON and -0.16 for MAM in Zone H; and of -0.028 for SON and -0.148 for MAM in zone ME. For zones K, F, and J only one season showed a clear temporal trend in rainfall amount (P>0.05).

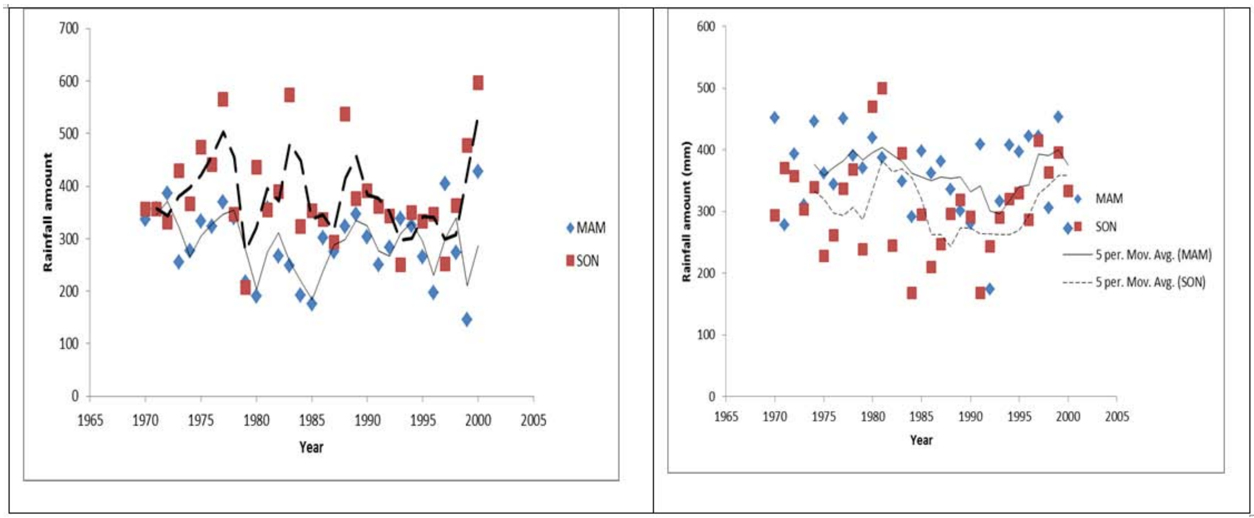



*Figure 3 :* Moving average trend in seasonal rainfall amount in climatologically homogenous rainfall zone ME (left) and zone H (right)

In zone A1, F, J and K, only MAM rainfall amount linearly changed overtime (P< 0.05) (Figure 4). For Zone F (Y=10.22t-19743; $R^2$=0.39, p<0.001) and A1 (Y=12.09t-23332; $R^2$=0.31; p=0.003) MAM rainfall amount increased significantly over the years; while in zone J (Y= -4.04t+ 8279.2; $R^2$=0.39, p<0.001) and K (Y=-6.33t+13263; $R^2$=0.49; P<0.001) it declined over the years. MAM rainfall tended to have a relatively high value of rainfall zone F and A1 than SON; an opposite trend was observed in zone K and J. The rainfall difference between MAM and SON in the three rainfall zones tended to increase gradually with time.

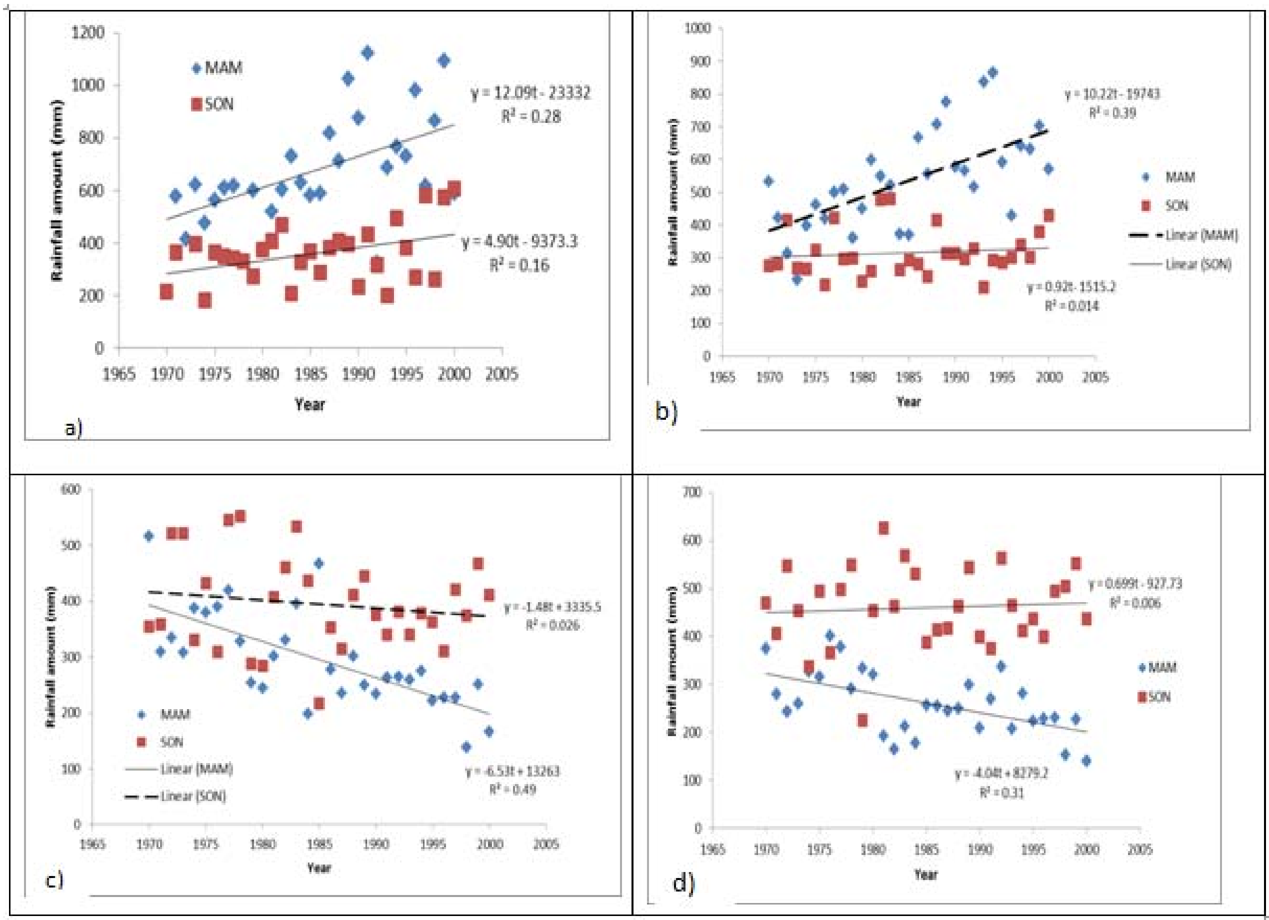



*Figure 4 :* Temporal trend in seasonal rainfall amount in climatologically homogenous rainfall, A1 (a) zone F (b); and K (c), zone J (d)

For D and L rainfall amount significantly varied for both MAM and SON ($P < 0.05$). For D both seasons showed a significant polynomial trend of power 3 in rainfall amount with a determination coefficient $R^2=0.47$ and 0.44 for SON and MAM; respectively. The first 15 years, MAM rainfall tended to have a relatively higher value than SON, and a relatively lower value for the next 15 years. In Zone L, both MAM and SON increased significantly over the years ($Y=10.68t+20637$, $R^2=0.50$, $p<0.001$ for MAM, and $Y=5.5t-10449$, $R^2=0.28$, $p=0.002$ for SON).

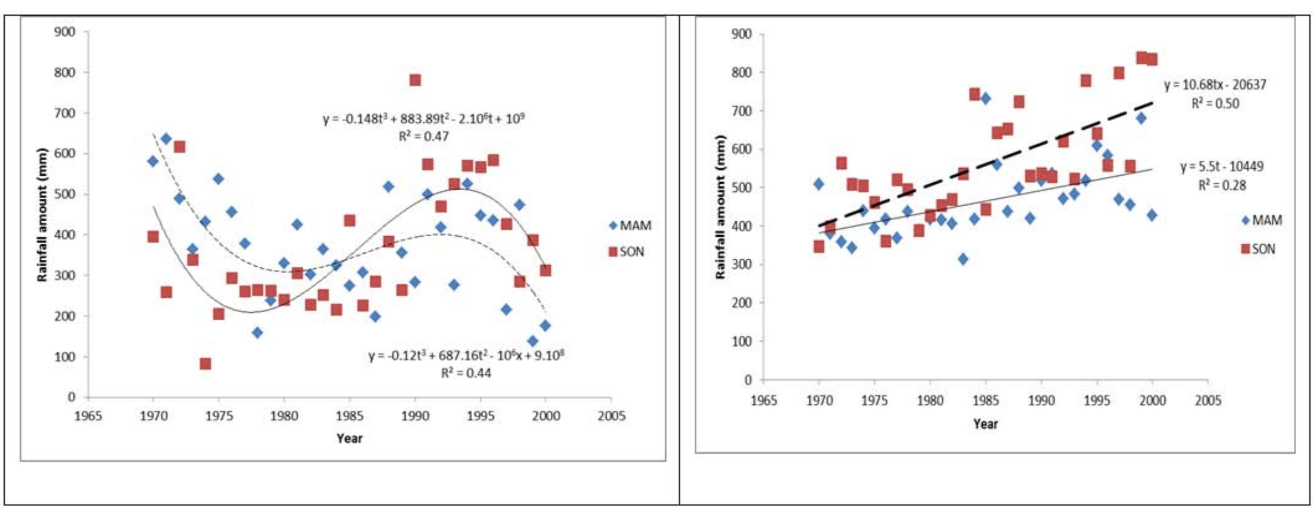



*Figure 5 :* Temporal trend in seasonal rainfall amount in climatologically homogenous rainfall zone D (left) and zone L (right)

The gradient of SON rainfall amount was relatively higher in zone L, implying an increasing difference between SON and MAM rainfall over the years in this zone. In zone E, though the two seasons showed an opposite linear trend, only the SON rainfall changed significantly over the years. The SON rainfall linearly increased with time ($Y=4.09t-7761.7$; $R^2=0.19$; $p<0.001$).

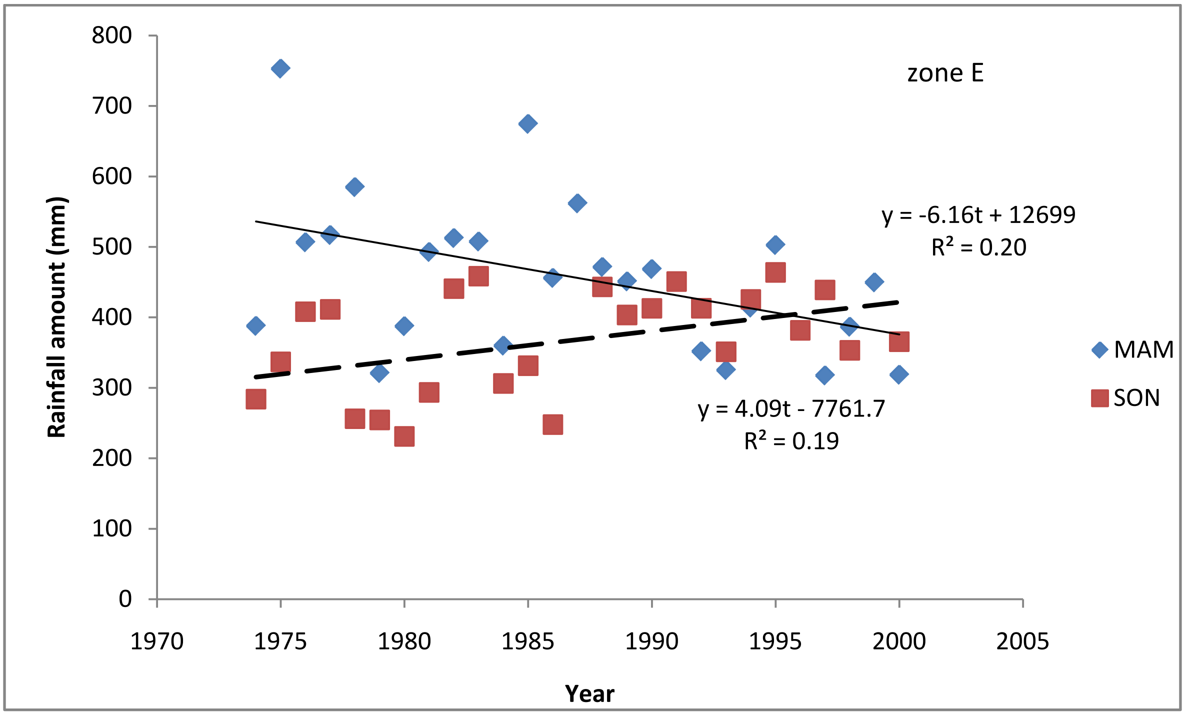



*Figure 5 :* Temporal trend in seasonal rainfall amount in climatologically homogenous rainfall zone E

For zones I, MW and A2 both seasons varied significantly with time, following different either quadratic shape for one and linear for the other one (Figure 6). For Zone I, the SON rainfall followed a quadratic shape ($Y=1.039t^2-4124.5t+ 4.10^6$; $R^2= 0.30$) with a minimum rainfall in 1985 while the MAM rainfall declined gradually over the year ($Y=-4.49t+9344.2$; $R^2=0.19$; $P=0.04$). For the zones MW and A2 the MAM followed a quadratic shape (($Y=0.69t^2-2733.1t+3.10^6$; $R^2=0.48$ for MW; $Y=0.44t^2-1725.1t+2.10^6$; $R^2=0.16$ for A2) and the SON varied gradually of the years ($Y=-4.41t+9030.2$; $R^2=0.24$) for MW; $Y=4.16t-7849.6$; $R^2=0.25$; $P=0.02$ for A2). The minimum MAM rainfall was observed around the year 1980 and 1982 for MW and A2; respectively.

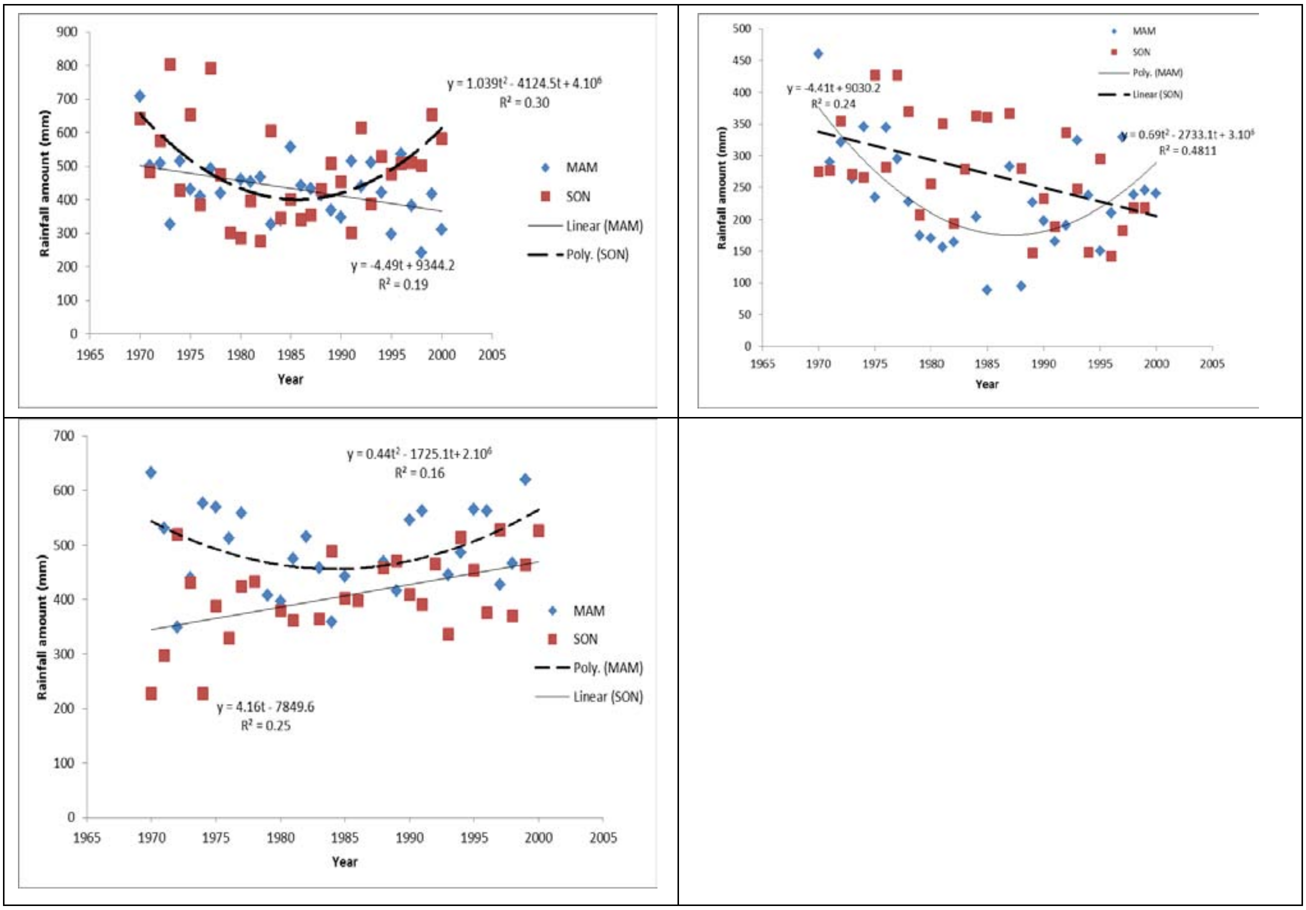



*Figure 6 :* Temporal trend in seasonal rainfall amount in climatologically homogenous rainfall zone I (a); MW (b) and A2 (c).

c) *Annual trend*

Annual rainfall averages varied across zones and ranged between 864.2 mm for Zone MW and 1618.4 mm for A1 (Table 3). ME and MW had the lowest average annual rainfall compared to the other zones. A1 had a relatively higher average annual rainfall amount compared to other zones, though not significantly different with that of the rainfall zone I. The latter average annual rainfall amount did not significantly differed from that of zone D. These were followed by the rainfall amount of zone A2, which in turn did not differ considerably from that of D and E. Zone E belonged to a group of zones (F, L, H and J) with no significant difference pairewise. The average rainfall amount for zone J did not considerably varied from that of zone K, though significantly higher than that of ME and MW. The CV for the studied period ranged from 12.8% for zone L to 27.2% for zone ME. Zones with CV less than 15% included K and A2, those with CV between 15% and 20% were D, F, H, I and J. Other zones such A1, E, ME had CV above 20%.

*Table 3 :* Descriptive characteristics of annual rainfall averages in the selected climatologically homogenous zones of Uganda (1970-2000)

| Zone | Mean (30 years) | Max (Min) | σ | CV |
|---|---|---|---|---|
| | (mm) | | | (%) |
| A1 | 1618.4ᵃ | 2679.2 (1139) | 329.8 | 20.4 |
| A2 | 1408.2ᵇᵈᵉ | 1633.1 (914.2) | 182.2 | 14.1 |
| D | 1500.5ᵇᶠ | 1904.0 (1072) | 235.9 | 15.7 |
| ME | 938.8ᶜ | 1353 (273.7) | 255.1 | 27.2 |
| MW | 864.2ᶜ | 1150.8 (582.9) | 140.1 | 16.1 |
| L | 1275.5ᵈ | 1826.2 (954.5) | 163.8 | 12.8 |

| | | | | |
|---|---|---|---|---|
| E | 1312.9[d] | 1844.5 (623.0) | 268.0 | 20.4 |
| F | 1256.1[d] | 1713.5 (768.5) | 236.5 | 18.8 |
| H | 1285.1[d] | 1908.6 (899.0) | 219.3 | 17.1 |
| I | 1529.6[af] | 2103.4 1134.1) | 237.8 | 15.5 |
| K | 1162.5[cg] | 1141 (853) | 153.4 | 13.2 |
| J | 1240.6[dg] | 1635.3 (616.2) | 218.6 | 17.6 |
| LSD | 110.5 | | | |

*σ: Standard deviation*

The annual rainfall amount did not show any significant linear trend (p>0.05) for all the studied rainfall zones, except zone A1 and K (Figure 7). For A1 annual rainfall amount increased significantly with time following the equation y=15.34t-28832 ($R^2$=0.18 and p= 0.02); while in Zone K it decreased significantly following the equation y = -7.06x + 15170 ($R^2$=0.18 and p= 0.019).

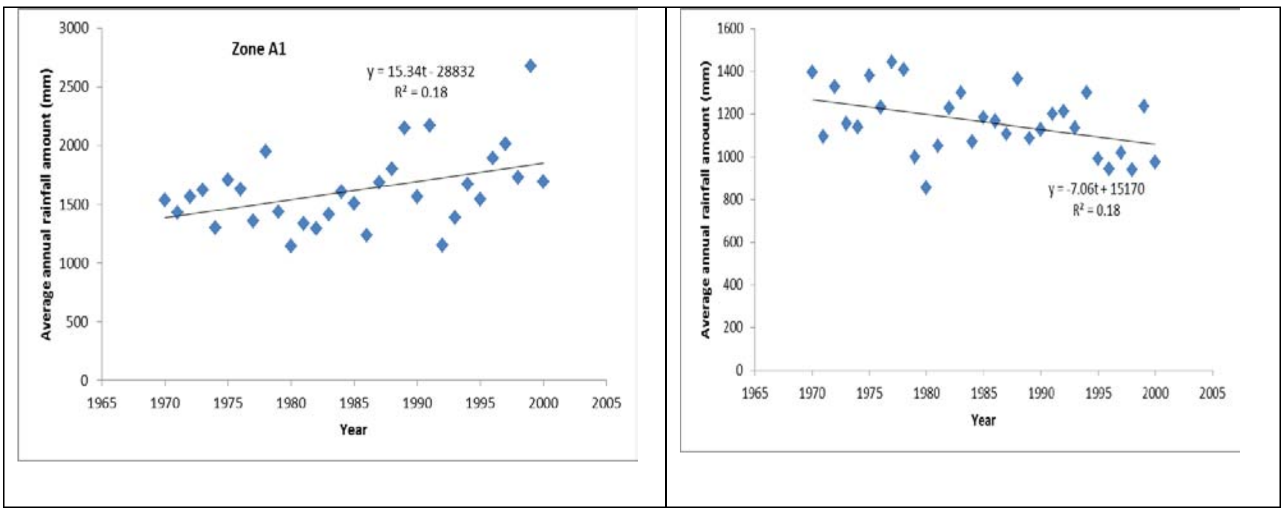



*Figure 7 :* Temporal trend in seasonal rainfall amount in climatologically homogenous rainfall zone A1 (left) and zone K (right).

The CV of all the studied rainfall zones showed significant trend over the years (P<0.05). For most the studied zones the annual rainfall amount variation increased gradually for A1, H, I, E, MW. It is linearly declining with time for zone D; and followed quadratic trend with a maximum between for A2, F, K and ME. All the other zones had a linearly increasing trend over time (Figure 8).

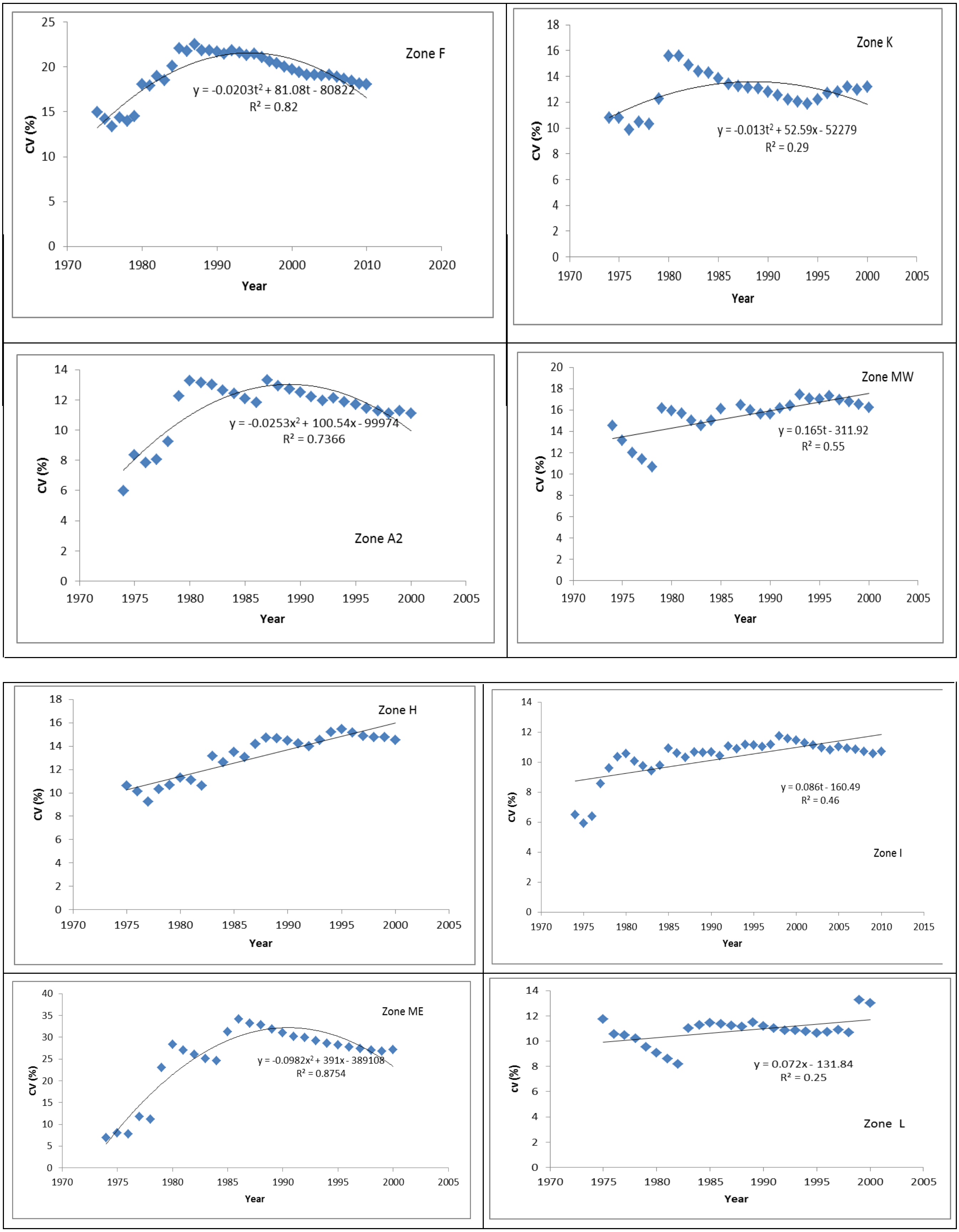



*Figure 8 :* CV of the annual rainfall amount in the studied homogenous rainfall zones

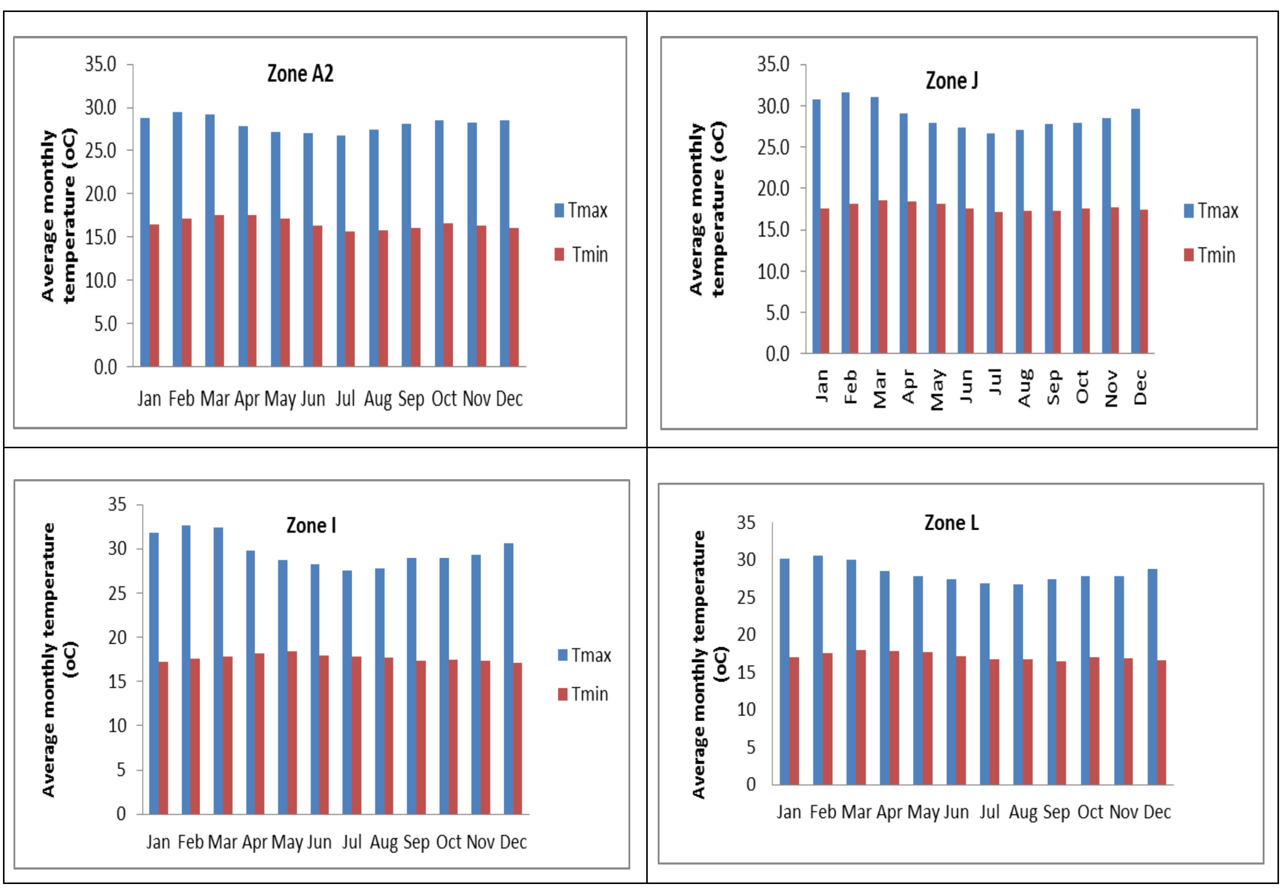
## IV. Maximum and Minimum Temperature

*a) Monthly temperature distribution*

The monthly maximum and minimum temperature distributions are depicted in Figure 9. Monthly maximum and minimum temperature values varied from one rainfall zone to another. Generally, both temperatures tend to be high from January to March for all zones. They decline progressively up to July before start increasing slowly up to December, except for A1, ME and F for which both maximum and minimum temperature presented peaks in February-March and August-September. The relatively lowest average monthly Tmax (26.17°C) was recorded in ME and the highest (36.06°C) in H. The relatively lowest average monthly minimum temperature (13.35°C) was recorded in F; while the relatively highest (20.76°C) in zone E.

*Table 4 :* Range of Tmax and Tmin for the studied rainfall homogenous zones of Uganda

| Zone | Temperature range (°C) | |
|---|---|---|
| | Tmax | Tmin |
| J | 28.11-34.05 | 17.56-19.08 |
| K | 28.78-31.63 | 17.72-18.62 |
| A1 | 26.13-26.93 | 17.82-18.46 |
| I | 27.51-32.61 | 17.14-18.39 |
| A2 | 26.78-29.43 | 15.69-17.53 |
| L | 26.78-30.56 | 16.53-17.95 |
| F | 26.31-28.80 | 13.35-15.32 |
| ME | 26.17-27.65 | 13.41-14.40 |
| E | 28.11-34.27 | 19.41-20.76 |
| D | 27.44-31.13 | 15.60-17.22 |
| MW | | |
| H | 29.18-36.06 | 17.29-19.60 |



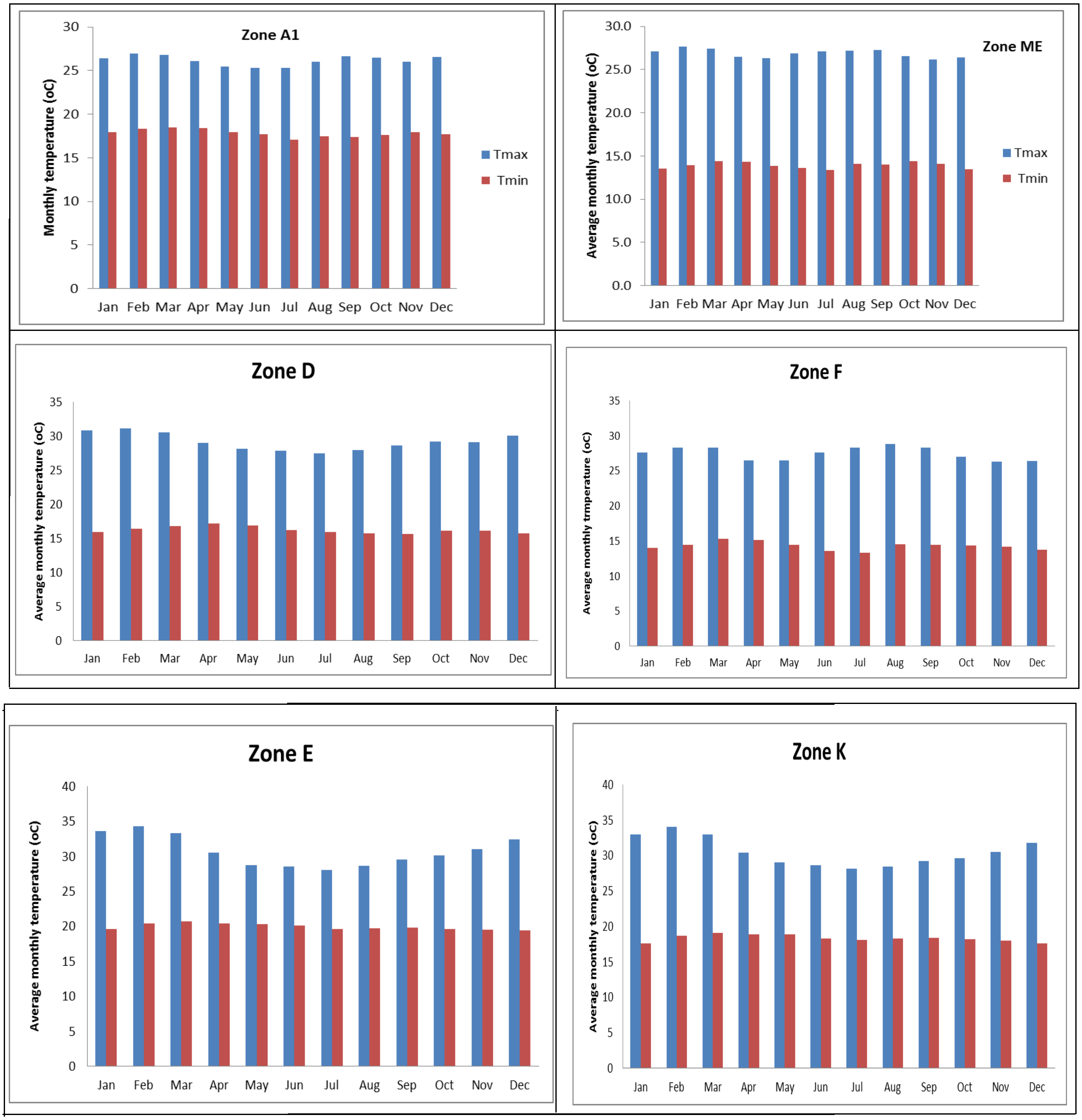



*Figure 17 :* Temporal trend in monthly temperature in selected climatologically homogenous rainfall of Uganda

*b) Seasonal trends*

Seasonal temperature variations were observed for the rainfall zones I, A1, L, D and E. In zone I, both Tmax and Tmin increased linearly for both seasons ($P<0.001$) with R2 ranging between 0.56-0.65 (Figure 9). For A1 and L seasonal temperatures increased linearly for both MAM and SON except for Tmax for SON ($P<0.05$) (Figure 10). For zone D, Tmax and Tmin increased linearly for both seasons ($P<0.05$). For zone L, Tmin for both MAM and SON increased with the time ($P=0.001$) with a similar gradient (0.035°C/yr) since 1970. For zone E, Tmax increased for MAM ($R^2=0.16$; $P=0.077$) and SON ($R^2=0.15$, $P=0.08$).

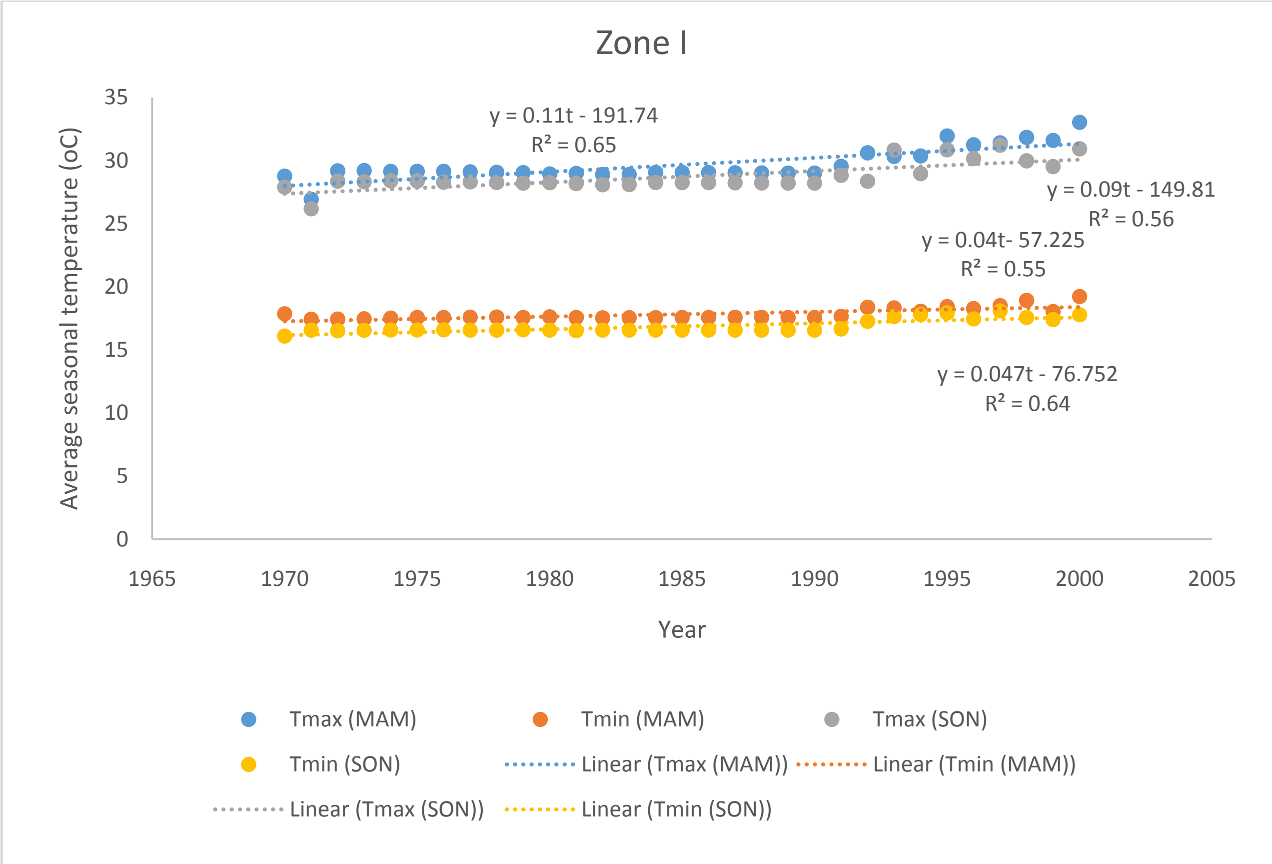



*Figure 9 :* Temporal trend in seasonal temperature in climatologically homogenous rainfall zone I

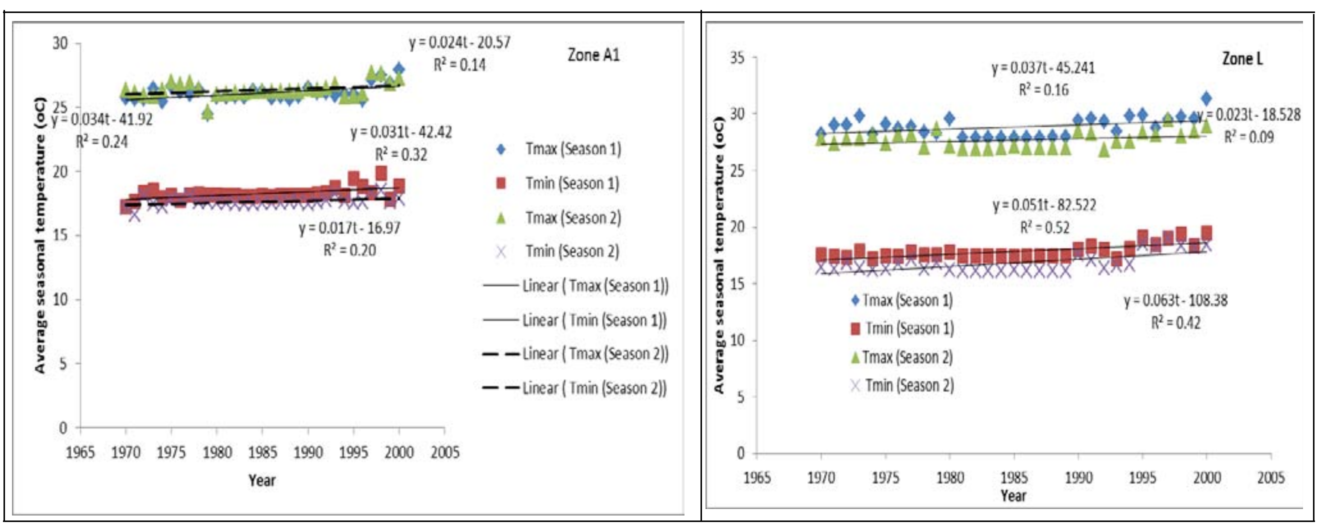



*Figure 10 :* Temporal trend in seasonal temperature in climatologically homogenous rainfall zone A1 (left) and L (right)

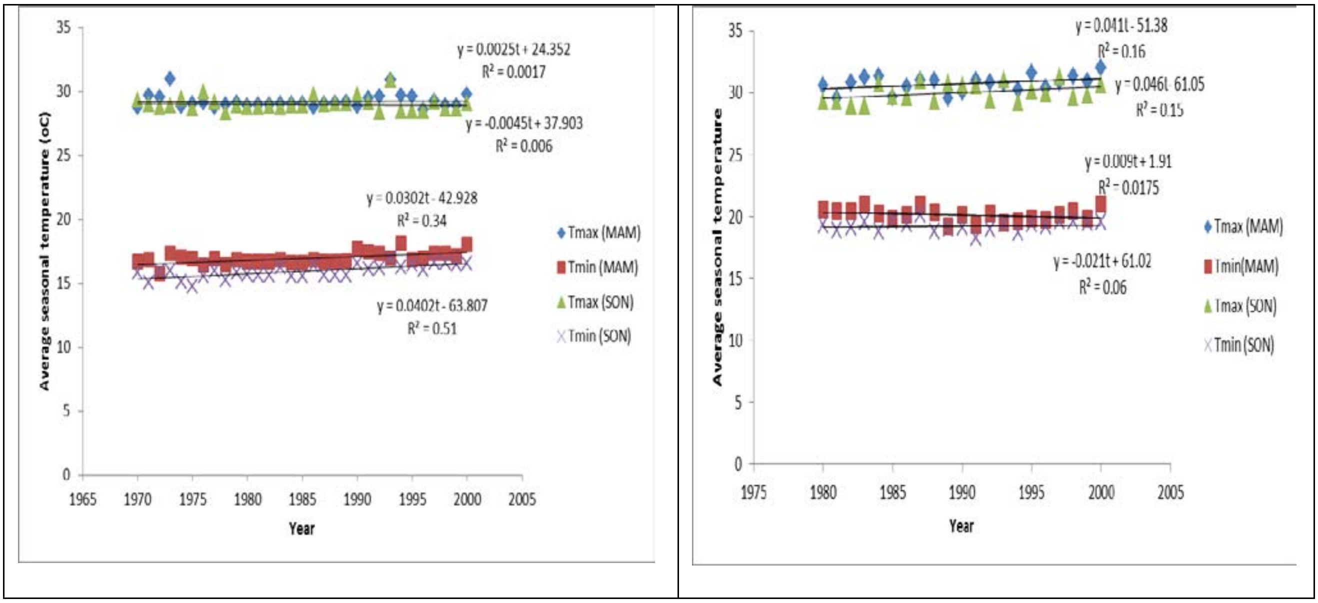



*Figure 11 :* Temporal trend in seasonal temperature in climatologically homogenous rainfall zone D (left) and E (Right)

Generally, there was very small variation (less than 1 °C) between average Tmax and Tmin in MAM and SON for a given zone; except for zone J and I were it was greater than 1 °C for Tmax, D, L and I for Tmin. In these zones, MAM tended to have a relatively higher temperature than SON. I most cases CV were very similar for both seasons for Tmax and Tmin, and below 5% except for zone ME.

*Table 5 : Descriptive statistics of average seasonal maximum temperature*

| Zones | MAM | | | | SON | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean (30 years) | Max (Min) | σ | CV | Mean (30 years) | Max (Min) | σ | CV |
| E | 30.71 | 32.00 (29.54) | 0.65 | 2.03 | 30.01 | 31.29(28.99) | 0.74 | 2.36 |
| A2 | 28.1 | 29.3 (26.7) | 0.63 | 2.23 | 28.3 | 29.2 (27.1) | 0.43 | 1.52 |
| D | 29.25 | 30.97 (28.57) | 0.55 | 1.87 | 29.0 | 30.87 (28.36) | 0.51 | 3.21 |
| F | 27.07 | 28.17 (26.09) | 0.58 | 2.12 | 27.21 | 28.51 (25.86) | 0.59 | 2.99 |
| L | 28.81 | 31.28 (27.88) | 0.85 | 2.95 | 27.71 | 29.44 (26.87) | 0.70 | 2.52 |
| J | 29.4 | 30.6 (28.0) | 0.64 | 2.19 | 28.1 | 29.0 (27.0) | 0.49 | 1.75 |
| MW | | | | | | | | |
| ME | 26.73 | 27.66(25.83) | 0.52 | 1.95 | 27.05 | 29.15 (25.60) | 0.83 | 3.07 |
| H | | | | | | | | |
| I | 29.66 | 33.02 (26.94) | 1.26 | 4.26 | 28.72 | 31,21 (26.18) | 1.09 | 3.18 |
| K | | | | | | | | |
| A1 | 26.11 | 27.92 (24.45) | 0.64 | 2.46 | 26.38 | 27.73 (24.66) | 0.58 | 2.21 |

*Table 6 :* Descriptive statistics of the average seasonal minimum temperature

| Zones | MAM | | | | SON | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean (30 years) | Max (Min) | σ | CV | Mean (30 years) | Max (Min) | σ | CV |
| E | 20.14 | 21.00(19.26) | 0.51 | 2.41 | 19.26 | 20.13 (18.32) | 0.41 | 2.03 |
| A2 | 17.4 | 18.6 (15.8) | 0.56 | 3.19 | 16.4 | 17.5 (15.6) | 0.54 | 3.03 |
| D | 16.95 | 18.11 (15.73) | 0.47 | 2.78 | 15.92 | 16.87 (14.77) | 0.51 | 3.21 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| F | 14.98 | 15.66 (14.30) | 0.37 | 2.48 | 14.35 | 15.15 (13.58) | 0.43 | 2.99 |
| L | 17.85 | 19.44 (17.17) | 0.64 | 3.57 | 16.84 | 18.97 (16.14) | 0.89 | 5.27 |
| J | 18.4 | 19.1 (17.7) | 0.36 | 1.98 | 17.5 | 18.0 (17.0) | 0.24 | 1.36 |
| MW | | | | | | | | |
| ME | 14.16 | 15.77 (11.40) | 1.13 | 7.99 | 13.73 | 15.80 (10.67) | 1.13 | 8.25 |
| H | | | | | | | | |
| I | 17.83 | 19.23 (17.43) | 0.46 | 2.59 | 16.88 | 18.09 (16.10) | 0.53 | 3.18 |
| K | | | | | | | | |
| A1 | 18.25 | 19.87 (17.23) | 0.49 | 2.69 | 17.65 | 18.5 (16.6) | 0.36 | 2.02 |





*c) Annual trend*

Annual variations in maximum and minimum temperatures are depicted in Figure 12 and 14. Three types of trends have been observed in the studied zones. In zone A1, A2, I and L, both annual average Tmax and Tmin have been increasing overtime (P<0.001). For zone K, E, F and D only one of the two average annual temperature showed a significant linear trend. For zone K, E and F, only Tmax showed a linear increase overtime while for zone D only Tmin had significantly increased with time. In other zones such as ME, L and J no significant linear trend was observed in both average annual temperatures.

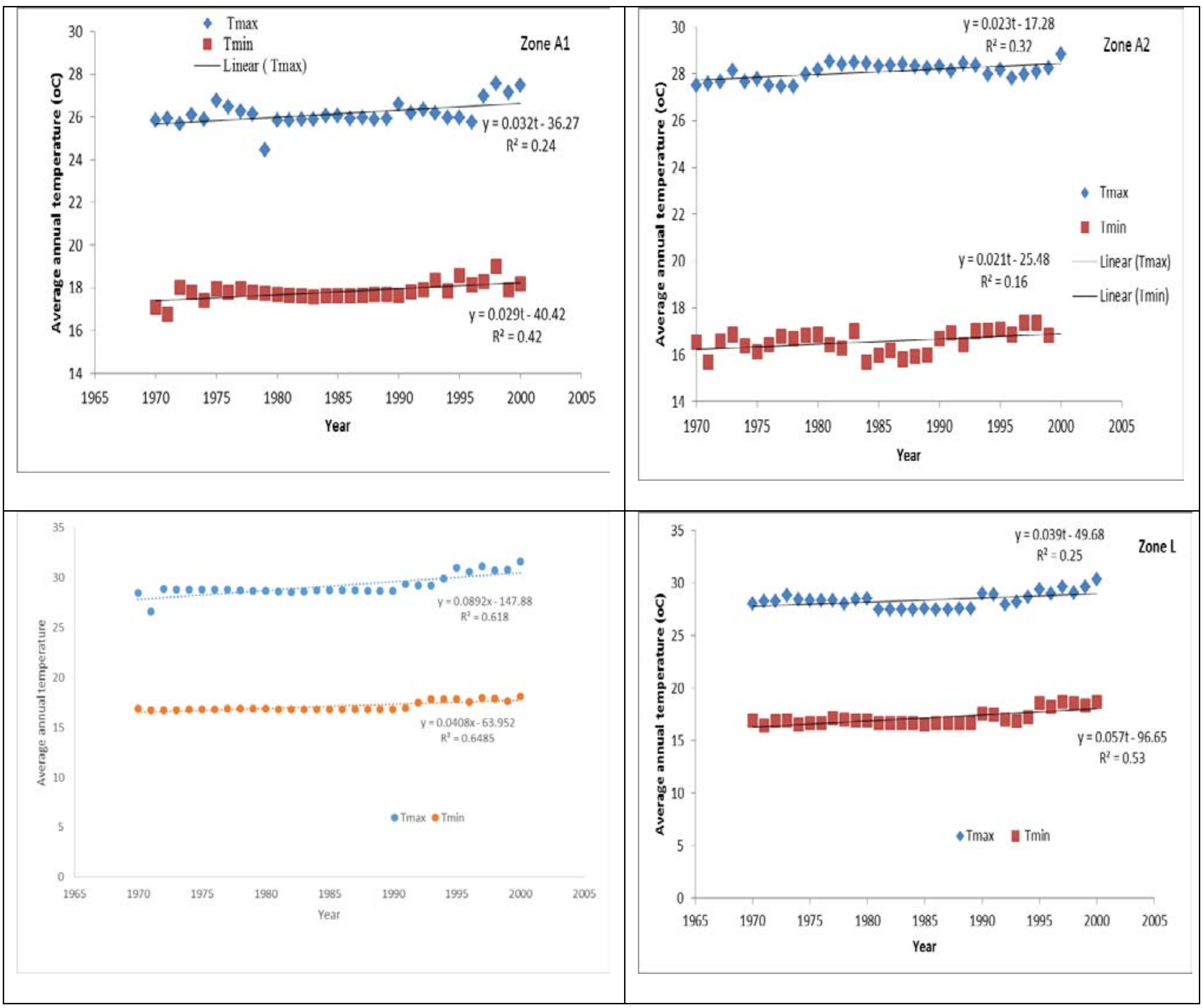



*Figure 12 :* Temporal trend in annual temperature in climatologically homogenous rainfall zone A1, A2, I and L

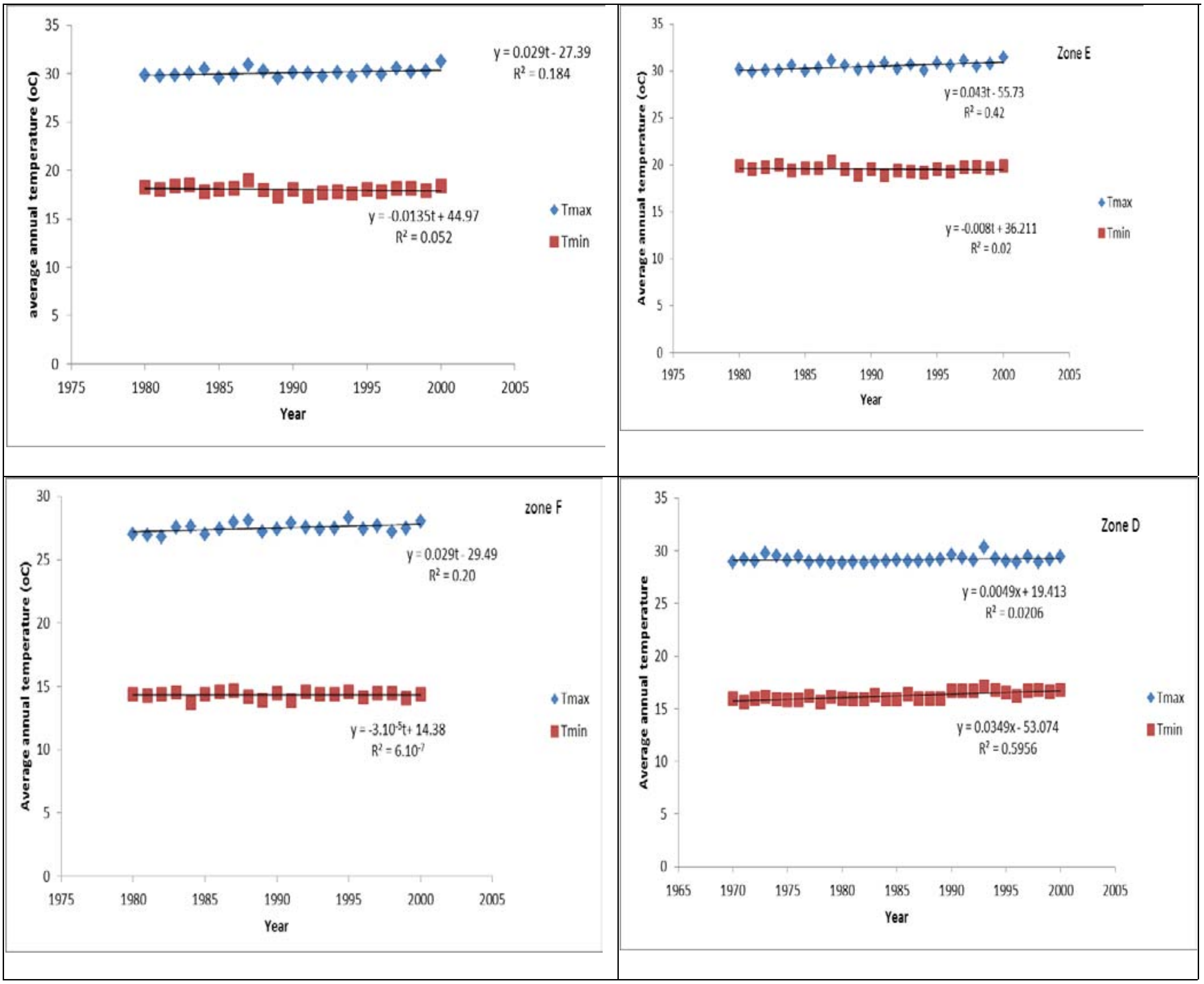



*Figure 13 :* Temporal trend in annual temperature in climatologically homogenous rainfall Zone K, E, F and D

## V. Discussion of Results

Apart from zones G, H and F, which exhibit a unimodal pattern with monthly maxima around JJA, all the other rainfall zones tend to behave bimodally, with a rainfall peak during MAM and a second during SON. This is in line with Kigobe *et al.* (2013) who observed that G, H and F tended to have unimodal pattern in the Kyoga basin. This bimodality is strong around the Equator, becoming less strong in the northern and southern regions of the country. The Inter Tropical Convergence Zone (ITCZ) driving southeasterly and northeasterly moist air currents from the Indian Ocean is the major seasonality factor (Nieuwolt, 1979; Mutai *et al*., 1998; Phillips & McIntyre, 2000). In Uganda, it has induced two seasons in the southern part of the country, and unimodal patterns towards the north, with the central part of the country as a transitional zone for the patterns observed in the north and south.

Seasonal and annual trend in rainfall varied from one zone to another, in term of magnitude and direction. Only Zones ME and H did not show any significant seasonal trend for the studied period. MAM increased for Zones A1 and F, and declined for J and K. For A1 and F, MAM rainfall tended to have a relatively high value of rainfall amount than SON; an opposite trend was observed in zone K and J. In zone E, the SON rainfall linearly increased with time. Our observations only corroborates Kansiime *et al.* (2013) findings that ASON rainfall amount increased in the Lake Kyoga basin, and MAM increase in zone F. We did not observed SON significant variation for A1 representing the Lake Victoria crescent nor a declining trend in MAM; perhaps because their definition of the long-rain season (MAMJ) which included the month of june. Our observations are also in line with Kigobe *et al.* (2013) observations in zone D were no significant seasonal trends was not observed.

The seasonal rainfall amount change was only significantly reflected for zone A1 and K. The annual rainfall amount increased significantly for A1 and declined for Zone K; respectively. Stampone et al. (2011) also observed that seasonal variations were not reflected in annual trends in their study of rainfall zones around Kibale national Park. This is attributed to several environmental factors (Horton, 1995) including topography, disparate and discontinuous land cover types, and seasonally distinct forcings on weather patterns, and proximity to large bodies of water (Ogallo, 1989; Meher-Homji, 1991; Basalirwa, 1995; Nicholson and Kim, 1997; Mutai *et al*.;1998; Indeje *et al*., 2000; Phillips & McIntyre, 2000). Other influences on rainfall variability include tropical storms, continental low-level troughs, extra-tropical weather systems and local meso-scale systems (Indeje *et al*., 2000). The role of land cover, most particularly vegetation cover and the effects of anthropogenic activities like deforestation cannot be overemphasised (Pielke, 2007; Webb, 2005; Meher-Homji, 1991). Deforestation affects rainfall through changing rates of physical evaporation, transpiration, surface albedo, and aerodynamic roughness (Pielke, 2001; Ray et al., 2006; Pielke et al., 2007). Vertical atmospheric motion forcing induced by topography in generation and modification of precipitation has been well studied (Roe, 2005; Smith, 2006).

The CV of all the studied rainfall zones showed significant trend over the years (P<0.05). It increased for all studied zones, declined for zone D and followed a quadratic trend with a maximum for F, K and ME. The magnitude of CV is in line with observations of Kansiime et al. (2013) in eastern Uganda. CV in this region was less than 30% for all locations they studied in eastern Uganda, and within the range of CV reported in the region. Seleshi and Zanke [10] obtained annual and seasonal rainfall (Kiremt and Belg seasons) CV values ranging between 10 and 50% in Ethiopia; were highly variable with CV values ranging between 0.10 and 0.50. Relatively high values (41%, 39% and 47%; respectively) have been recorded in for Machang'a, Kiritiri, and Kindaruma in Kenya (Kisaki et al., in press). This high variability have been connected to sea-surface temperature (SST) gradient fluctuations, especially the El Niño Southern Oscillation (ENSO) (; Shisanya, 1990; Mutai *et al*., 1998; Indeje *et al*., 2000; Mutai & Ward, 2000; Anyamba et al., 2001; Ntale & Gan, 2004). ENSO teleconnections affect the northern and southern regions of Uganda differently. In the south, El Niño leads to higher rainfall amounts and emphasizes the bimodal pattern, while La Niña leads to lower rainfall (Phillips & McIntyre, 2000). In the north of the basin, El Niño is associated with depressed July–September rainfall amounts and an increase in October–December rainfall, while La Niña has exactly the opposite effect. Some studies also link the annual variability of East African rainfall amount to Indian Ocean SST and corresponding wind anomalies (the Indian Ocean Dipole Mode) (Saji *et al*., 1999; Iizuka *et al*., 2000; Black *et al*., 2003).

Temperature trends also varied from one rainfall zone to another. Average Tmax and Tmin increased linearly for both seasons for I and D. For A1 and L only Tmax for SON did not show significant variation (P<0.05). For zone L, the MAM Tmin significantly increased gradually for both seasons; while for zone E, Tmax increased only for MAM. The annual Tmax and Tmin increased linearly with time for zone A1, A2, and L. For zone K, E and F, only Tmax increased linearly with time; while for zone D only Tmin had significantly increased with time. As for rainfall, the change in temperature in the studied rainfall zones is linked to the ~1°C warming in the Indian Ocean and overturning circulations bringing dry hot stable air masses down across parts of the Horn of Africa ( Funk and others, 2008; Williams and Funk, 2011; Williams et al., 2011). It has been consistent and persistent over the 1950-present era, and is uniformly reproduced by all the IPCC climate models and several different precipitation time series (Williams and Funk, 2011; Adler et al., 2003; Kanamitsu *et al.* 2002; Xie and Arkin 1997; Chen et al. 2003; Smith et al. 2010). Funk *et al.* (2008) suggested that the warming in the Indian Ocean is likely to be at least partially caused by anthropogenic greenhouse gas emissions.

## VI. Conclusions and Recommendations

In light of the above results and discussions we conclude that rainfall and temperature trends have varied from one rainfall zone to another in Uganda. Seasonal variations in rainfall have been observed in A1, F, K and J inter annual variations have been detected in most of the studied rainfall zone. While temperature variations have been observed in rainfall zone A1, A2, K, E and F. The variability in rainfall places increased climatic pressures on the agricultural sector in Uganda, the backborne of Uganda's economy. Effort should be made to take advantage of the increasing trend in rainfall amounts in certain zones and promote best management practices to cope up with the negative impacts related with the variation in climatic parameters.

## VII. Acknowledgements

This study was carried out with the generous technical and financial support provided by ICRISAT, AGMIP, the Department of Meteorology and Climate Unit in Uganda. We are gratefully recognizing the support of Dr. Alex Ruane for the AgMERRA.

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