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Temporal and Spatial Characteristics of the June-August Seasonal Rainfall and Temperature over South Sudan

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ABSTRACT

Climate extremes including drought, floods, and high/low temperatures are recurrent in South Sudan and they are associated with widespread socio-economic miseries. This study aims at enhancing our understanding of past and present characteristics of climate extremes over South Sudan based on the temporal patterns of the past rainfall and temperature extremes.

The datasets used in this study were monthly rainfall and temperature for period 1954 to 2013. Temperature records included both maximum and minimum values. Graphical methods and statistical techniques such as Mann Kendall statistics, Spectral analysis, Standardized Precipitation Index (SPI) and Gaussian kernel function were used to investigate the past and present characteristics of rainfall and temperature.

It was found that the rainfall over South Sudan is uni-modal with its peak in the months of July and August with June through to August (JJA) being the main rainy season and contributing more than 50% of annual rainfall. Highest maximum temperatures were recorded in April while the lowest minimum values were recorded in the months of December and January.

Results from trend analysis showed a decline in the JJA seasonal rainfall trends in many locations. However, both the maximum and minimum temperature indicated a significant increasing trend for all locations considered in the study at 0.05 significance level although with some slight seasonal differences in the patterns of the increasing trends.

The inter-annual patterns of rainfall indicated recurrent patterns of floods and droughts over all locations of South Sudan. Two distinct spectral peaks of rainfall and temperature were common in all locations centered at 3-5 to 7-9 years. The Probability distribution function showed a shift of the entire distribution towards the dry climate conditions for rainfall and warmer climate for maximum and minimum temperatures.

The findings of this study showed key indicators of climate change signals over South Sudan. These findings can help policymakers to mainstreaming climate related risks into national policies, plans, and development projects. Further work should be done to strengthen these findings by use of observed gridded dataset and projected future climate based on the Global /Regional Climate Model (G/RCMs).

Key words: *rainfall, temperature, spatial, temporal, extremes, South Sudan*

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1. INTRODUCTION

Climate variability and change impacts are being felt daily in many parts of the world. The impacts are likely to worsen in future when the extremes are projected to become more severe and more frequent. No sustainable development can be achieved without addressing the challenges of climate variability and change. IPCC (2013a) assessment report have confirmed that climate change is real with increasing frequency and intensity in extreme climate events such as drought, flood, heat waves, and sea level rise among many others (IPCC, 2013b).

Rainfall and temperature are the most important and sensitive climatic elements in tropical regions and information about their characteristics, especially the extremes are critical in the planning and management of most socio-economic activities. The frequency of occurrence of extremes in temperature and precipitation is expected to increase during the next century (IPCC, 2013b). Knowledge on the characteristics of past, present and future rainfall and temperature are vital and forms the basic background to anticipate all climate related risks as well as providing early warning systems for early intervention actions to reduce the negative impacts as well as taking advantage of the positive ones in support of sustainable development efforts.

Eriksen et al (2008) reported that Africa has experienced a 0.5 °C rise in temperature over the course of the 20th century, with some areas warming faster than others. Rainfall over most parts of Africa has been noted to exhibit spatial and temporal variability with great inter-annual rainfall variability (Ogallo, 1979; Nicholson, 2000; Hulme et al, 2005). The temperature variability over Africa during the last 2000 years recorded an increase of greater than 0.5° C during the last 50-100 years with minimum temperatures warming more rapidly than maximum temperatures *(*Nicholson et al, 2013*)*. Near surface air temperature anomalies were significantly higher for the period 1995–2010 compared to the period 1979–1994 (Collins, 2011). The major extreme climate events that are categorized under extreme precipitations and temperature include floods, drought, and heat waves which do affect property, society and the entire ecosystems in different ways.

Study on long term climate prediction and seasonal rainfall over the Greater Horn of Africa (GHA) revealed increase in variability of seasonal rainfall that makes it less predictable (Nicholson, 2014). A number of studies have shown that rainfall and temperature over East Africa depict large temporal and spatial variability during 20th century. For example, Williams and Funk (2011) highlighted that over the last three decades, rainfall has decreased over eastern Africa between March and May/June, due to rapid warming of the Indian Ocean which causes an increase in convection and precipitation over the tropical Indian Ocean, thus contributing to increased subsidence over eastern Africa and a decrease in rainfall during March to May/June period.

The study carried out by UNEP (2007), USAID (2007) and IFAD (2009) to assess Sudan Post-Conflict Environmental situation, identified climate change as one of the most critical threats to the development of Sudan. This situation was confirmed partly through a study by Mojwok (2008) which investigated the effects of rainfall fluctuations on rain-fed agricultural production in Renk area and Upper Nile State as a representative of South Sudan cultivation areas. His results showed a strong relationship between the agricultural production and rainfall performance. The results further indicated the positive/negative effects of extra-ordinary rainfall performance and Agricultural production.

Based on a study carried out by Famine Early Warning Network (FEWS NET, 2011), their results indicated that Darfur in western Sudan and most parts of South Sudan have experienced a 10-20 per cent decrease in rainfall trends since the mid-1970s. The long-rain season, the period during which relatively heavy and steady rains are experienced, typically occurs in Darfur and South Sudan from June through September. Long-rains are crucial to the region's main harvest. Since the 1960s, however, drought has become more frequent and more widespread during these months (Funk et al, 2005; Elagib and Elhag, 2011). Between the 1960s and late 2011 the area received adequate rainfall (more than 500 mm) which supported agro-pastoralist livelihoods that had been reduced by 18 per cent due to the reduced rainfall (Funk et al, 2011). In these semi-arid and dry sub-humid zones, rain-fed agriculture is already strained due to the seasonality of rainfall, intermittent dry spells and frequent drought years (SEI, 2005). In addition to the 30-year trend of declining precipitation, there is evidence that variability in amount and timing of rainfall from year to year is increasing, which would further compound food insecurity in the region (Elagib and Elhag, 2011; Pohl and Camberlin, 2006; Elagib, 2009).

The analysis and reviews of rainfall trends and variability in some locations in upper Nile state were carried out by Edward (2011) and Chan (2011). Their findings showed a decline in rainfall trends and an increase in temperature over most locations during some seasons. This situation in South Sudan resulted in rainfall deficiency, intensity and timing, shift in the onset and cessation, high temperature and wind, low humidity levels and cloud cover which exacerbated meteorological drought resulting to massive economic, social and environmental impacts. This situation has been observed in many parts of South Sudan particularly Malakal county (Chan, 2011). For instance, the drought which occurred in 1983 and 1984 were the most extreme drought in recent history. This drought coincided with the start of civil war, which accelerated the drought impacts that included crop failure and food insecurity. The drought caused a widespread of diseases, loss of more than 55,000 people's lives, and destruction of ecosystem and biodiversity especially the nomadic tribes that loss thousands of livestock (Osman and Shamseldin, 2002).

This study attempts to provide in-depth analysis on the temporal and spatial characteristics of rainfall and temperature over South Sudan.

2. DATA AND METHODOLOGY

This section presents the area of the study, data used together with methods that were adapted in the study

Study area and data used

South Sudan covers an area of 619,745 sq. kms, located in northeast of Africa. Before 9 July 2011, it was part of the larger Sudan. South Sudan lies between latitudes 3° and 13° N, and longitudes 24° and 36° E. The country is mainly plain interrupted every so often by hilly areas with thick equatorial vegetation and savannah grasslands. The country also has mountainous ranges along its border with Uganda. Some of these include Imatong, Didinga and Dongotona, which rise more than 3,000 meters above sea level. The River Nile that passes across the country is the dominant geographic feature in South Sudan.

The South Sudan's climate is mainly tropical; the climate ranges from semi-arid in the north to tropical wet- in the far southwest. The country is generally hot with seasonal rainfall driven by the annual north-south shift of the Inter-Tropical Convergence Zone (ITCZ). The main factors and systems influencing climate over South Sudan include the position and intensity of the Inter-Tropical Convergence Zone (ITCZ), sub-tropical high pressure systems in the southwest Indian Ocean (Mascarene High), the St. Helena High in the southeast Atlantic Ocean, Azores/Sahara High in the North Atlantic Ocean and Arabian High to the northeast, Inter-hemispherical monsoonal wind systems, Easterly and Westerly waves, and teleconnections with El-Niño Southern Oscillation (ENSO).

The climatic data used in this study include gauged datasets (historical monthly rainfall totals and monthly mean temperature records, covering period (1954 to 2013) for five synoptic stations; namely El renk , Malakal , Raja , Wau and Juba. These data are obtained from South Sudan Meteorological Department (SSMD). The stations locations and other details are showed in Figure 1

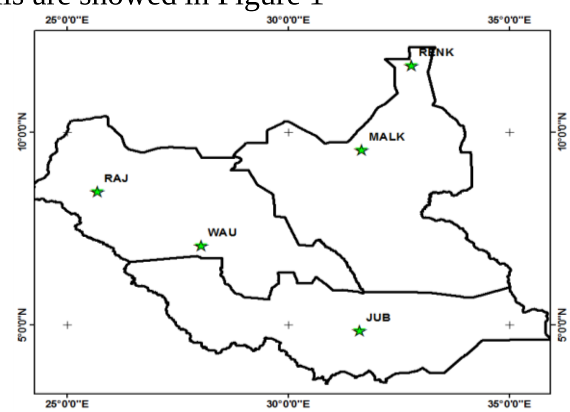


***Figure 1**: The study area with the location of the stations used in the study*

Methodology

Standardization of the Climate Records

In order to compare data from various locations and different variables like temperature and rainfall is critical that such data be standardized. The Standardized Rainfall Anomaly Index (SAI) was used in the analysis of June, July and August (JJA) rainfall and temperature variability. The data are standardized by taking the difference of each dataset from the mean for a particular time step, and then dividing it by the standard deviation as mentioned in Equations below:

The mean $\left(\bar{x}\right)$ of a variable is averaged sum of all observations with respect to time.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} X_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The variability is computed using the square root of variance (standard deviation) and is denoted as σ ;

$$\sigma_x = \sqrt{\frac{1}{n}\sum_{1}^{n}\left(x_i - \bar{x}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\mathrm{SAI} = \frac{X_i - \bar{X}}{\sigma_x} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where,

X_i is the annual rainfall total, $\bar{X}$ is the mean of the entire series, and σ is the standard deviation from the mean of the series.

Trend analysis

Trend presents the long-term movement of the time series. It is the underlying direction (an upward or downward tendency) and rate of change in a time series. Trend patterns can be derived from graphical and statistical techniques (Ogallo, 1980; Ogallo, 1981; Omondi, 2005; Muthama et al, 2008). The trend analysis in this study was achieved through graphical and statistical techniques

I. Graphic method

The Graphical display method plots the smoothed and unsmoothed time series of the individual data for the specific locations year to year graphs of the time series. Graphical method is highly subjective, requiring any observed trends to be subjected to statistical tests.

II. Statistical methods

The statistical methods included arithmetic mean, regression analysis, and Man Kendal statistics. Under arithmetic method, the data is divided into several sub periods each of at least 30 years, and arithmetic averages of the sub-periods computed and compared for each location.

Regression analysis fitted a, linear regression equation to the time series graphs and the regression slope tested for significance. Trend is significant if the slope is significant.

For a time series, the Mann Kendall statistic S is given as;

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn(X_j - X_i) \ldots\ldots\ldots\ldots(4)$$

Where X_i and X_j are sequential data values, **n** is the dataset record length and $sgn\ (X_j - X_i)$ is +1, 0 and −1 for $X_j - X_i$ greater than, equal to or less than 0 respectively. The significance level, which indicates the strength of the trend, was determined by resampling analysis while the Kendall's correlation coefficient which is a measure of the strength of the correlation is calculated using Equation 5.

$$\tau = \frac{2S}{(n(n-1))} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

A positive value of τ indicates increasing trend and vice versa (Hirsch et al., 1982).

Spectral analysis

Spectral analysis has been used extensively to examine whether time series of any meteorological parameters dataset exhibited any periodic fluctuations. The most common methods of computations include autocorrelation transform, fast fourier transform, and maximum entropy method (Jenkins and Watts, 1968; Cooley et al, 1967; Burg, 1972; Ogallo, 1982; Gitau, 2005). In this study the faster Fourier transform technique which is mathematical method for transforming a function of time into a function of frequency was employed. The significant spectral peaks were tested at 95% confidence level using white noise hypothesis (Jenkins and Watts, 1968). These methods employed to determine the spectral-peaks, corresponding to periodicities in the annual and seasonal rainfall and temperature (maximum and minimum) time series. Tukey-hamming window was used to smooth spectral estimates. Details of spectral analysis technique may be obtained from Jenkins and Watts (1968), Cooley et al (1967) and Burg (1972). Applications of the method for various time series analysis over eastern Africa may be obtained from Ogallo (1982), Gitau (2005) among many others.

Standardized Precipitation Index (SPI)

The standardized precipitation index (SPI) is a drought index first developed by Lloyd-Hughes and Saunders (Costa, 2011). The SPI is used for estimating wet or dry condition based on precipitation variable. Positive SPI values indicate wet condition greater than median precipitation, whereas negative values the dry condition less than median precipitation. For the purpose of this study, the SPI was computed on 12-months' time scale. Positive SPI values reflect wet conditions while negative values indicate a drier climate. State definitions are given in Table 1. The SPI were computed and their space-time patterns used to examine the past patterns of droughts in South Sudan.

***Table 1**: Classification scale for the SPI values: McKee et al., 1993; Lloyd-Hughes and Saunders, 2002)*

Severity of dry conditions	Description of state	SPI values	Severity of wet conditions	Description of state	SPI values
	Extreme drought	$SPI \le -2$		Near normal	$-1 < SPI < 1$
	Severe drought	$-2 < SPI \le -1.5$		Moderately wet	$1 \le SPI < 1.5$
	Moderate drought	$-1.5 < SPI \le -1$		Severely wet	$1.5 \le SPI < 2$
	Near normal	$-1 < SPI < 1$		Extremely wet	$SPI \ge 2$

Probability of Occurrence of Extremes

Probability distributions of annual and seasonal rainfall and temperature in South Sudan analyzed using Gaussian kernel function were computed and compared for two sub periods 1954-1983 and 1984-2013. The degree of smoothing is determined by a smoothing a parameter "b" values which is rate of exchange between residual error and local variation (Räisänen and Ruokolainen, 2008). For $b = 1$, the kernel returns a normal distribution with the same mean and standard deviation. For $b \neq 1$, the mean increases/ the variance increases or both the mean and variance increase. Changes in the distribution of the Gaussian kernel function were also generated from simple climatological statistics including maximum values divided by minimum values; range (mathematically maximum minus minimum values); first moment which is mean in other words; second moment (variance divided by Standard Deviation (SD)); Coefficient of variation (Mean divided by SD); third moment (Skewness coefficient in other words) and fourth moment (kurtosis coefficient). Some of these changes are demonstrated in Figure 2. The parameters for the two sub periods 1954-1983 and 1984-2013 were be computed and compared in this study

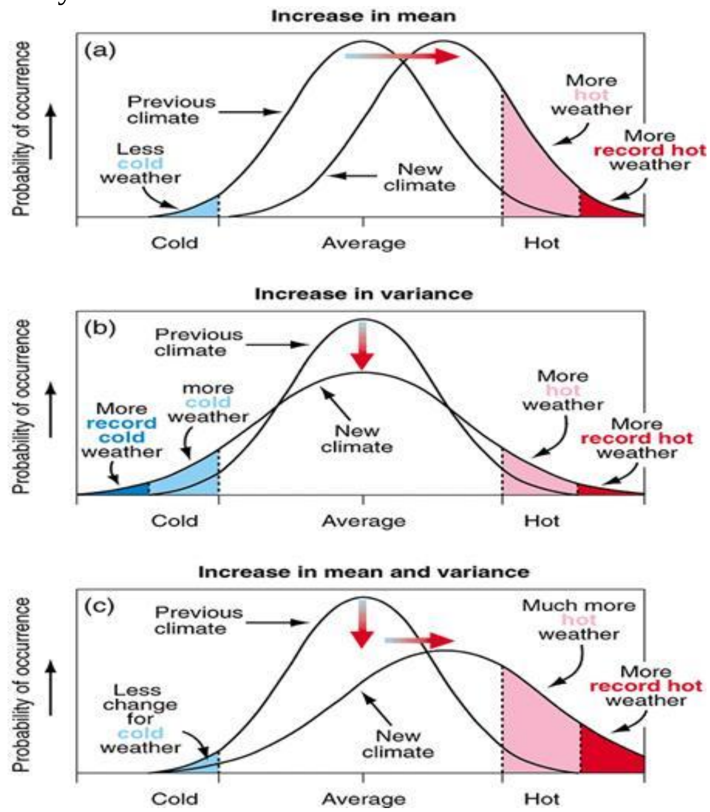


***Figure 2**: Schematic showing the effect on extreme temperature when (a) the mean increases, leading to more record hot weather, (b) the variance increases, and (c) when both the mean and variance increase, leading to much more record hot weather.(Source:IPCC,2012)*

3. RESULTS AND DISCUSSION

3.1 Monthly and Seasonal Rainfall and Temperature Climatology

Figure 3 shows the Mean annual cycle of rainfall and temperature climatology (1961-1990). It can be seen that the rainfall is uni-modal over South Sudan, with a peak in July and August. The main rainy period in southern parts of country starts from March to November compared to northern parts where rainy period start from May to October (Figure. 3 (a)). There were however some evidences of reducing rainfall amounts in July with some increase in August at many locations. The highest levels of maximum temperature were recorded in the months of April in northern part of country, March in western parts and February in southern parts and exceeding 37 °C whereas the lowest levels of maximum temperature were recorded during months of July and not exceeding 32 °C over all parts of country (Figure. 3 (b)). The highest levels of minimum temperature were recorded during months of April in northern and central, May in western and March in southern parts of country, whereas the lowest levels of maximum temperature were recorded during the months of December and January over all parts of country (Figure. 3 (c)).

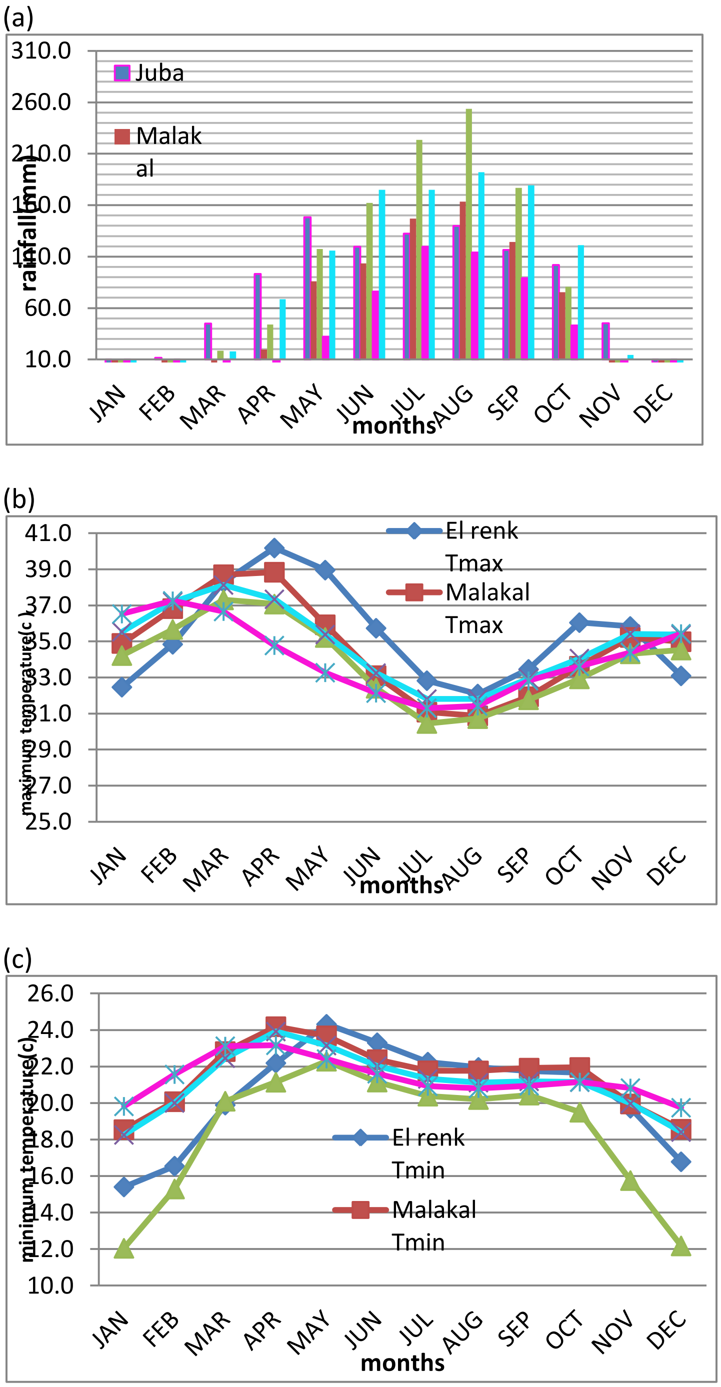
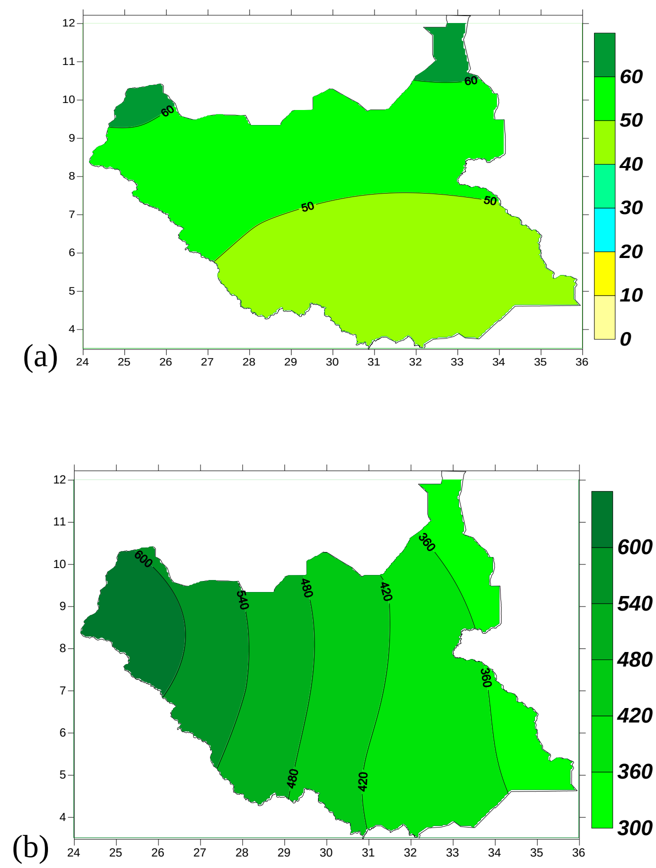
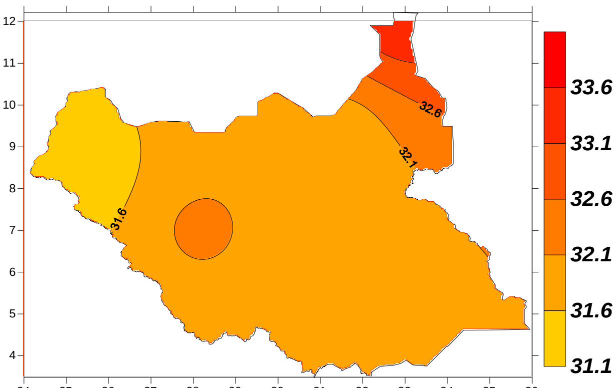


***Figure 3**: Mean annual cycle of rainfall and temperature: (a)Rainfall,(b)Maximum temperture ,(c)Minimum temperature.*

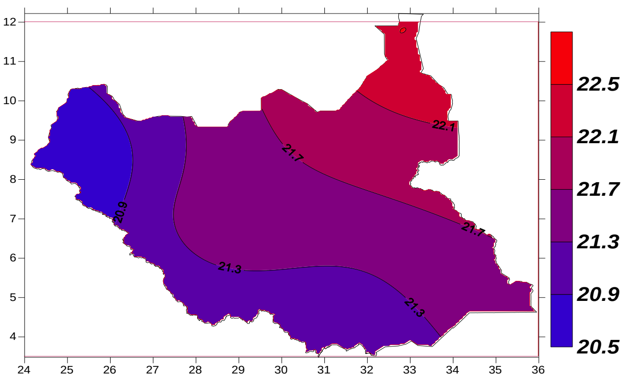
The spatial patterns of rainfall and temperature for June to August (JJA) season are presented in Figure 4. The results indicate that JJA season is the main rainy season in South Sudan and thus a key season for agricultural activities. The rainfall patterns show a decrease in rainfall amounts from west to east with a seasonal average range of 300 mm in north-east and south-east, while western parts recorded above 500 mm (Figure. 4 (a)). The JJA contributes more than 40%, 50% and 60% of annual rainfall in southern, central and extreme northern parts of country respectively (Figure. 4 (b)).

The maximum and minimum temperature differences were notably small across the country. The extreme north recorded the highest maximum temperature but not exceeding 34°C (Figure. 4 (c)), while western part recorded the lowest minimum temperature of around 20°C in average (Figure. 4 (d)). The observed high variability in temperatures across the country can be attributed to activities of convective cloud and vegetation cover.





(c)



(d)

Figure 4: *Mean seasonal rainfall and temperature climatology: (a) JJA Rainfall climatology,(b) JJA contribution to annual rainfall (%),(c) JJA Maximum temperature climatology, (d) JJA Minimum temperature climatology relative to 1961-1990.*

In order to capture the rainfall and temperature trends and regularity, the differences in seasonal rainfall and temperature (maximum and minimum) for the current period (1984-2013) relative to (1954-1983) and (1961-1990) were computed (Figures 5). The results indicated that there is a considerable increase in rainfall and temperature in some locations and a decrease in others with respect to the two periods with the rate of change differing from location to another. The southern parts of the country recorded a small decrease in the mount of current rainfall compared to northern parts which had a slight increase in current rainfall relative to both periods under consideration.

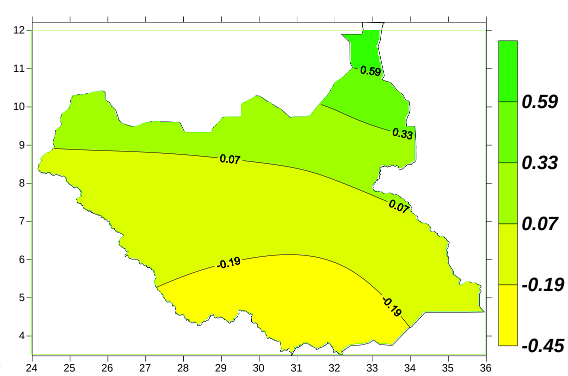
The changes in maximum temperature indicated a slight warming in current period relative to (1954-1983), while southwest showed a slight cooling relative to (1961-1990) with the northern parts of the country warming more compared to southern parts. The minimum temperature for current period (1984-2013) had increasing anomalies over the southwest with other parts experiencing a cooling relative to both (1954-1983) and (1961-1990).The decline in the amount of rainfall and the increasing maximum and minimum temperatures in the current period compared to previous periods can be attributed to the direct effects of global warming and is clear evidence of climate change signal over South Sudan.

3.2 Observed Rainfall and Temperature Trends

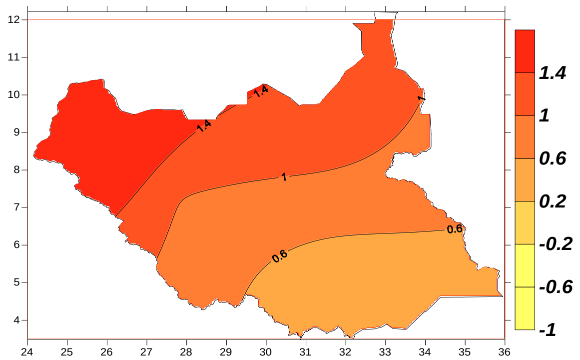
Both graphical and statistical techniques were used to examine trends in rainfall, Maximum and Minimum temperatures in this study. The observed trends for rainfall time series are shown in Figure 6. The results indicate that the JJA rainfall anomalies exhibit insufficient statistical evidence of a decreasing trend in all parts of South Sudan except the extreme north represented by Renk that showed an insufficient statistical evidence of an increase in rainfall trends at the 0.05 level of significance.

The observed trends for maximum temperature are shown in Figures 7. The results show that there is a statistical significance of increasing trends for most locations considered in the study at the 0.05 level of significance. Same trends were noted for minimum temperature as was the maximum temperature with an exception in northern part that had an insufficient evidence of an increase in minimum temperature at the 0.05 level of significance (Figures 8).

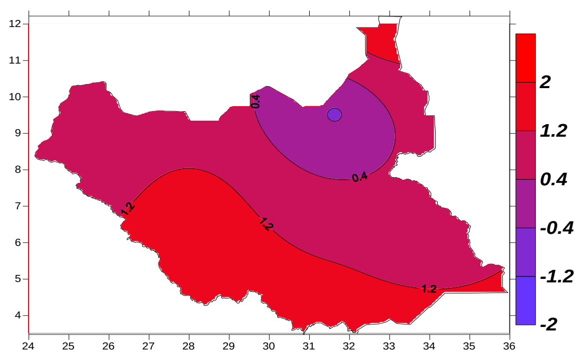
The decreasing trends of JJA seasonal rainfall and increasing temperature trends are clear indicators of climate change and global warming in South Sudan. This warming is expected to continue in the next decades due to the projected increase in the anthropogenic forcing.



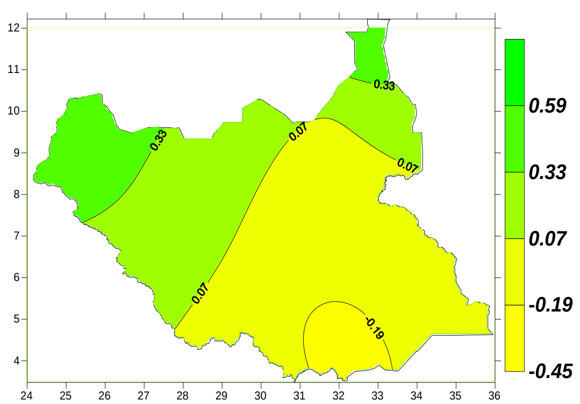
(a)



(b)



(c)



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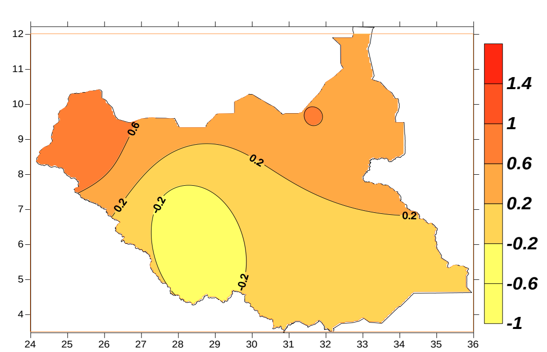
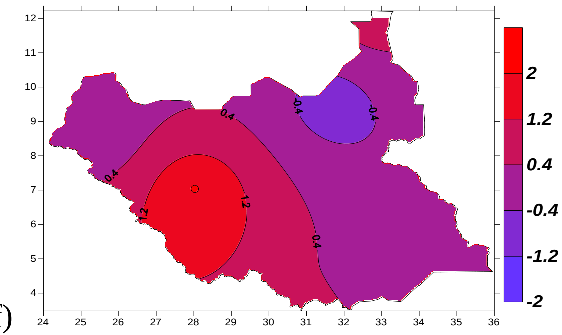


(e)



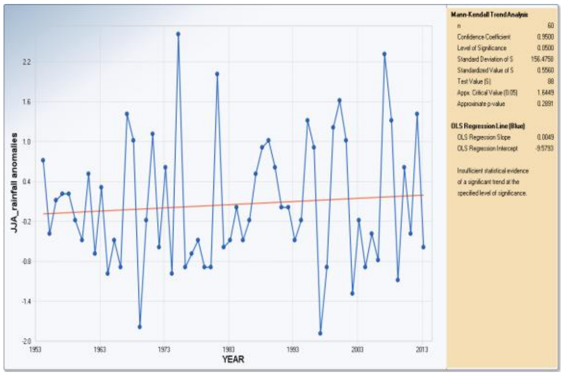
(f)

***Figure 5**: Observed changes in mean JJA seasonal rainfall and temperature for the current period 1984-2013 relative to 1954-1983 (a,b,c) and 1961-1990 (d,e,f)*

These changes in rainfall and temperature trends have both positive and negative environmental, economic, and social impacts. Household incomes of a majority of families in South Sudan are dependent on rain fed agriculture and pastoral activities. Therefore, adaptation measures should be put in place to reduce the vulnerability and strengthen the resilience of communities to cope with these changes and variability.

These results agrees with the findings by Nicholson *et al*. (2013), which concluded that there is variability of temperature during the last 200 years and a significant increases during the last 50-100 years over most parts of Africa with minimum temperatures warming more rapidly than maximum temperature. Funk *et al*. (2005; 2011), FEWS NET, (2011) further confirmed that Darfur in western Sudan and much parts of South Sudan have experienced a 10-20 per cent decrease in rainfall trends since the middle of 1970s, while the 1960s and late 2011, the area received adequate rainfall (500 mm) that supported agro-pastoralist livelihoods that had been reduced by 18 per cent due to the reduced rainfall. Further, there is evidence that variability in amount and timing of rainfall from year to year is increasing (Elagib and Elhag, 2011; Pohl and Camberlin, 2006; and Elagib, 2009).

(a)



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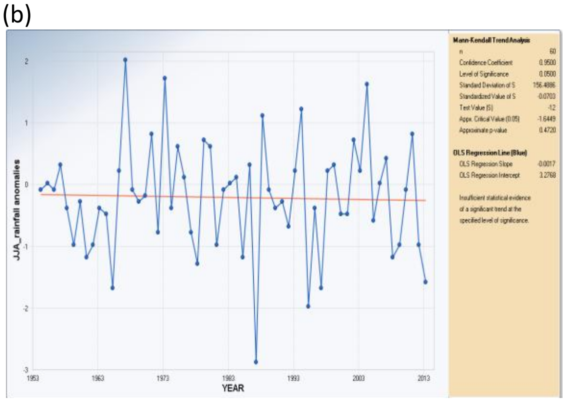
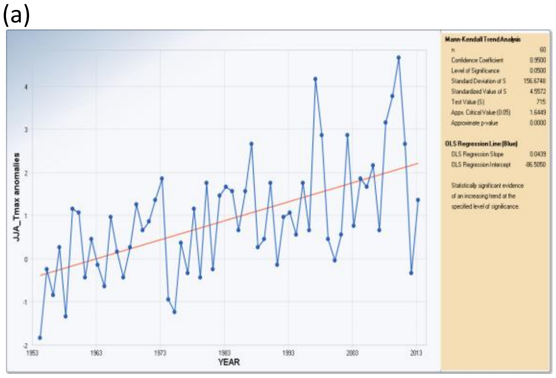


Figure 6*: Time series of Observed JJA rainfall Anomalies for selected stations (a) Renk (b) Juba.*

(a)



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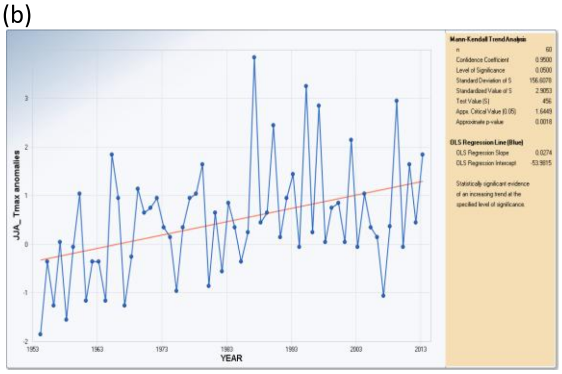
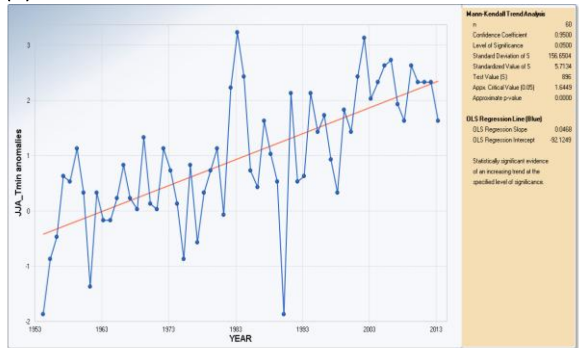


Figure 7*: Time series of Observed JJA maximum temperature Anomalies for selected stations (a) Malakal (b) juba*

(a)



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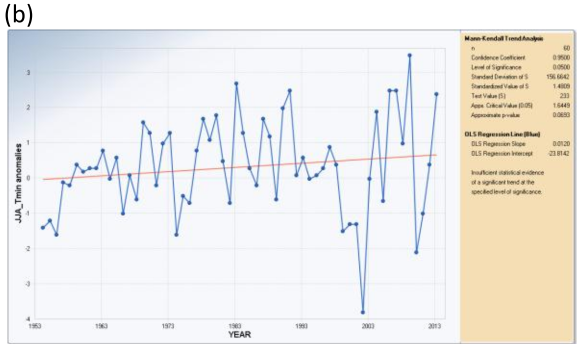


Figure 8*: Time series of Observed JJA minimum temperature Anomalies for selected stations (a) Renk, (b) Juba****.***

3.3 Cyclical variation in rainfall and temperature time series

The observed spectral peaks in seasonal rainfall and temperature anomalies are presented in Figures 9. Generally, the results for rainfall and temperatures show a significant spectral peak at 95% significance levels.

For rainfall, the results indicate that there is recurrence of spectral peaks in most of the stations considered in study but not exceeding 3 peaks. The proportion of the total rainfall variance accounted for by each spectral peak varied significantly from one region to another. Most of JJA seasonal rainfall spectral peaks occurred between 2 to 10 years. The period range of two spectral peaks were centered on 2 to 5 years, and observed in most of stations considered in study especially the northern parts of country.

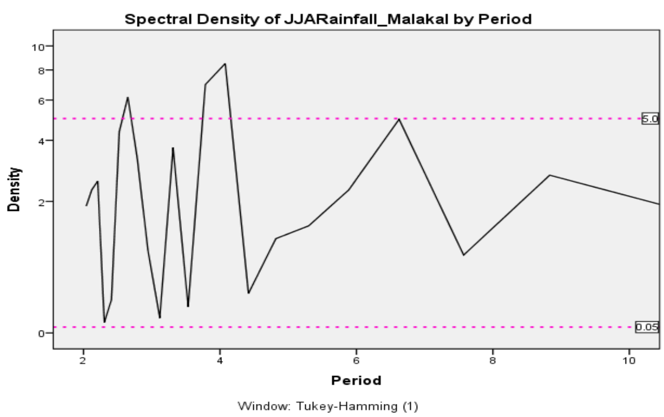
The results obtained from spectral analysis of the JJA seasonal maximum temperature for selected stations revealed that there is a recurrence of one spectral peak in most of the stations considered in study. The proportion of the total maximum temperature variance accounted for by each spectral peak varies significantly within season and a region to another.

Spectral peaks occurred between 2 to 5 years, with the significant ones occurring after three years.

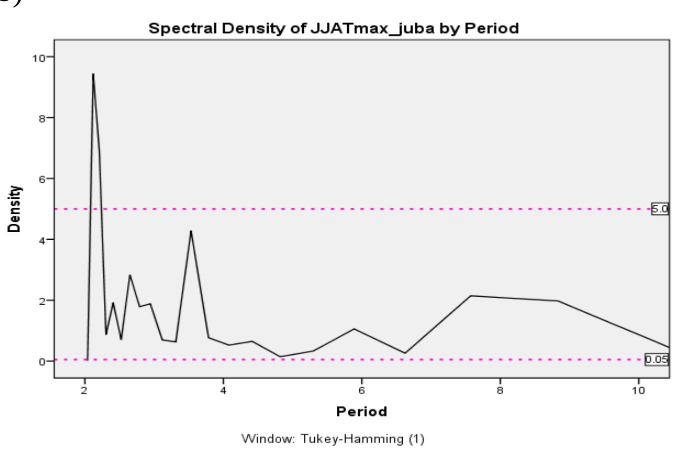
The results obtained from spectral analysis of seasonal minimum temperature showed that there is recurrence of spectral peaks in most of the stations considered in study but not exceeding 1 significant peak with a time range of between 2 to 4 years. The period ranges of the 2 spectral peaks were centered on 3 to 4 and 5 to 7 years.

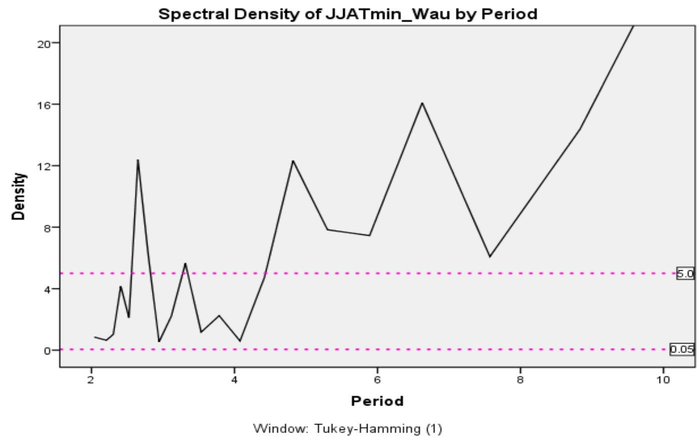
The observed fluctuations in the rainfall and temperatures can be attributed to some common large scale forcing mechanisms within the atmosphere and ocean components such as Quasi-Biennial Oscillation (QBO) in the lower stratospheric zonal winds, El Niño and La Niña events especially those fluctuation occurring with a periodicity of 2 to 3 years. Further, some local systems such as altitude, nearness to water bodies, local circulations like meso-scale circulations of thermal or terrain origin can play some significant role in the spatial distribution of the rainfall variance (Ogallo, 1982).

(a)



(b)





(c)

Figure 9: *Observed spectral peaks in JJA seasonal rainfall and temperature: (a)Rainfall,(b)Maximum temperature,(c) Minimum temperature.*

3.4 Standardized Precipitation Index

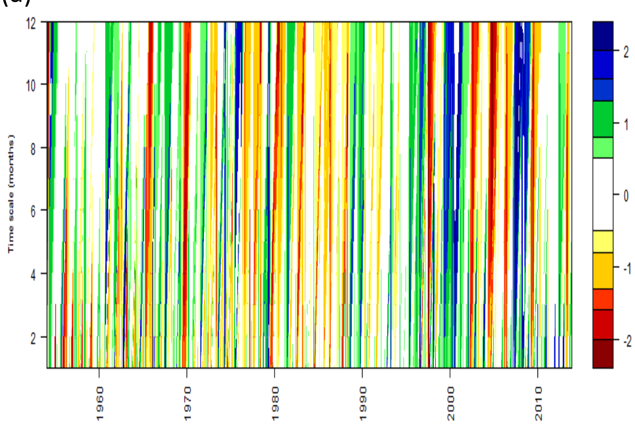
Figure 10, shows the Standardized Precipitation Index (SPI) for two locations selected in the study namely Malakal and Juba. The results indicate that the highest number and intensity of drought occurrences were experienced in the period 1980 - 1990 especially 1982 to 1985, while floods occurred in the 1960s and 2000s. Further, there is an increase in the rate of extra-ordinary flood years from 2000s to the recent years over most parts of South Sudan.

SPI in extreme north of the country indicated no extreme drought. However a severe drought occurred in 1971 and 1990 and a moderate one occurred in 1983, 1984, 1987 and 1998. The recurrence of extreme floods occurred in 1963 and 1998, severe floods occurred in 1992, 2005 and 2007, moderate floods occurred in 1961, 1981, 1989, 1994, 1997, 1999 and 2006, extreme floods occurred in 1975, 1999, 2000, 2007 and 2002, severe ones occurred in 1996 and 2008 and moderate floods occurred in 1966, 1967, 1981, 1989, and 1995. Nine out of the last 15 years recorded an increase in the number of extreme climatic events (drought and floods events) in the extreme north.

In the Northeast of the country, the extreme drought occurred in 2004 while severe drought occurred in 1965, 1969 and 2002 and a moderate one in 1977, 1980, 1982, 1985, and 2005. The recurrence of extreme floods occurred in 1975, 1999, 2000, 2002 and 2007, severe cases occurred in 1996 and 2008, and moderate ones occurred in 1966, 1967, 1981, 1989, and 1995. Nine out of the last 15 years recorded increases in the number of drought and flood events in Malakal. Northwest of the country had extreme drought in 1966 and 1969, severe one in 1987 and 1995, moderate drought occurred in 1980 and 1983. The recurrence of extreme floods occurred in 1963, severe floods occurred in 1965, 1976 and 1997, and moderate floods occurred in 1961, 1968, 1978, 1996, 2007 and 2013. Central parts of the country recorded extreme drought in 2009 and 2010, severe drought in 1971, 1990, 1994, 2000 and 2011, and moderate drought in 1972, 1981, 1983 and 1986. The recurrence of floods was extreme in 1966 and 2013, severe in 1962, 1964 and 1997, and moderate in 1963, 1969, 1987, 1995, 2001 and 2006. SPI analysis for southern parts had extreme drought in 2004, severe drought occurred in 1965, 1969 and 2002 and moderate drought in 1977, 1980, 1982, 1985 and 2005. The recurrences of floods were extreme in 1962, 1967, 1988 and 1999, severe in 2002 and 2011 and moderate in 1996 and 2003. Nine out of the last 15 years recorded an increase in the number of drought and flood events in Malakal.

Extreme climate events have negative influences on socio-economic sectors, especially activities dependent on rainfall. Therefore, adaptation measures such as improving crop varieties, water harvesting and conservation will greatly enhance resilience and reduce the risk of these shocks to agricultural related activities. A comprehensive assessment on the effect of these extremes in terms of losses to life, economic malaise and impact on the country's gross domestic product (GDP) needs to be undertaken.

(a)



(b)

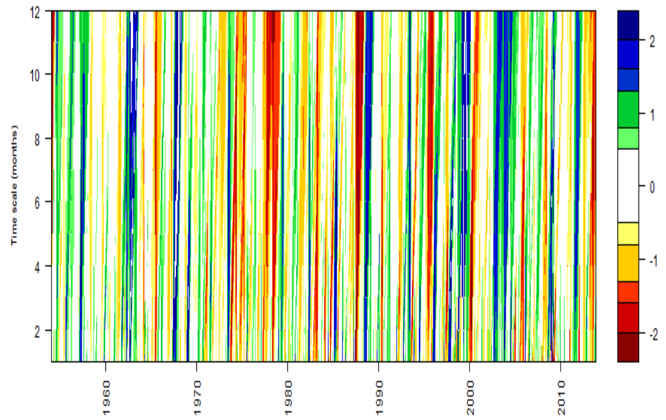


***Figure 10**: Standardized Precipitation Index (SPI) for selected stations: (a) Malakal, (b) Juba*

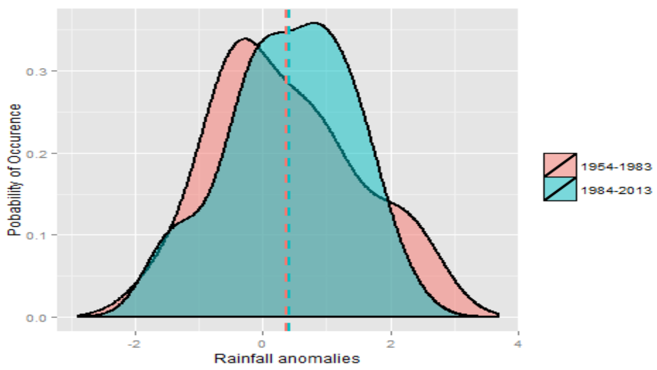
3.5 Probability distribution of rainfall and temperature in a changing climate extremes

Figures 11 and 12 show results obtained from the Gaussian kernel distribution of rainfall, maximum and minimum temperatures Long Term Means (LTM) of two periods 1954-1983 and 1984-2013 for JJA seasonal rainfall and temperature.

In general, results showed four main probability distribution patterns namely a simple shift of the entire distribution toward wettest/driest for rainfall and a warmer/colder climate for temperatures (maximum and minimum), effects of an increase in rainfall and temperature variability with no shift in the mean and effects of an altered shape of the distribution, which can be an asymmetrical shift toward the hotter/colder part of the distribution.

For rainfall, results revealed slight increase in recurrence of extremes with small shifts of long term means towards the wettest direction in the extreme north parts. The rest of the country had a slight increase in extremes with a shift of long term means towards the driest direction with an increase in variance and no shift in mean. Shifting in long term mean to wettest/driest differed from what happened to the extremes at either end of the distribution (Figures 11).

(a) slight increase in mean (towards wettest)



(b) increase in variance (no shift in mean)

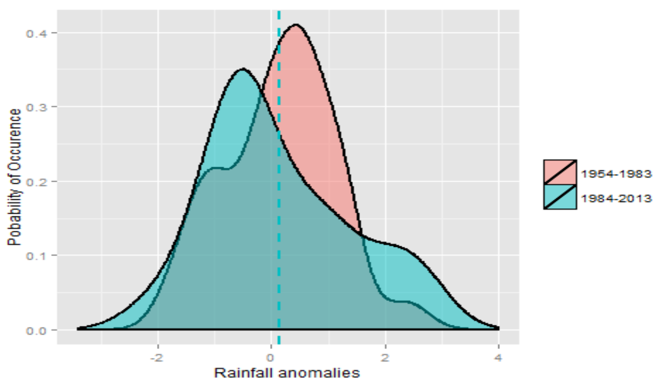
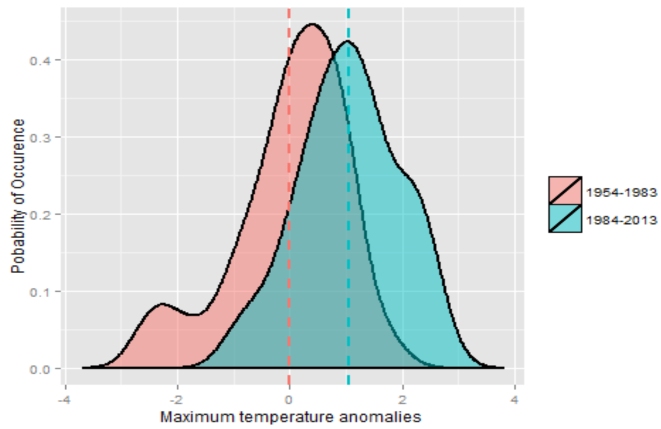


Figure 11*: The effect of changes in JJA rainfall distribution on extremes: The Area shaded in pink is long term mean for 1954-1983 and the Area shaded in light sky blue is long term mean for 1984-2013 for (a) Renk, (b) Malakal*

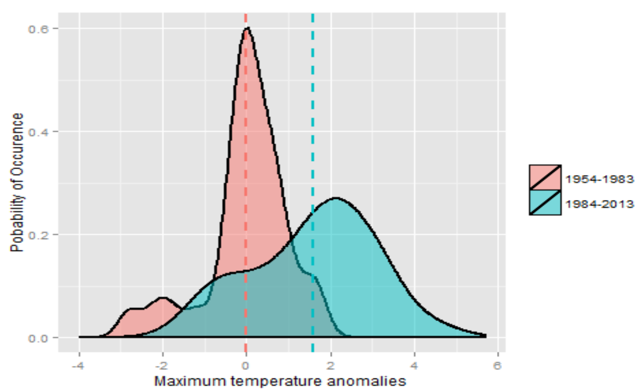
For maximum and minimum temperature, the results showed very clear evidence of a shifting temperature towards warmer conditions with a significant increase in mean towards hottest, increase in mean and variability and recurrence of warm conditions (Figures 12).

The relationships between the changes in mean rainfall and temperature and the corresponding changes in the probabilities of these extreme rainfall and temperature events are quite nonlinear, with relatively small changes in mean rainfall and temperature sometimes resulting in relatively large changes in event probabilities. All stations considered in the study showed a shift in the long term mean of annual and seasonal rainfall and temperature associated with increase in mean and variance that resulted in substantial changes in the frequency of occurrence of extreme drought, floods and heat waves. For a normally distributed variable such as temperature, a small increase in its long-term mean, and/or variance, can produce substantial changes in the probability of occurrence of extreme heat (IPCC, 2007; IPCC, 2012; IPCC, 2013a).

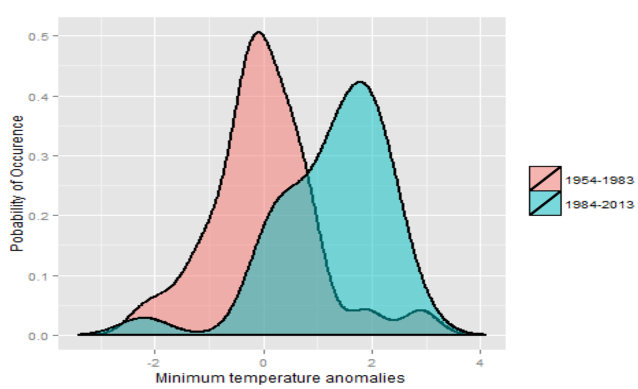
(a) increase in mean (towards hottest)



(b) increase in mean and variability



(c) increase in mean(towards hottest)



(d) increase in mean and variability

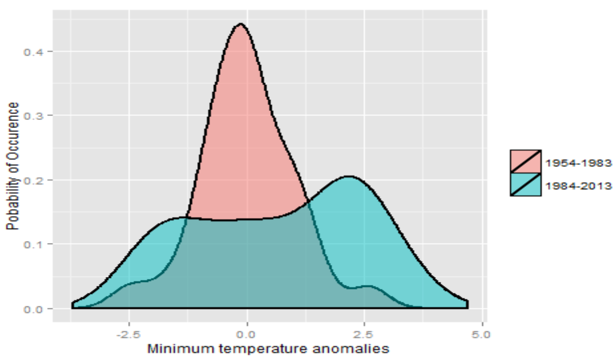


Figure 12: *The effect of changes in JJA maximum temperature(first row) and minimum temperature(second row) distribution on extremes: The Area shaded in pink is long term mean for 1954-1983 and the Area shaded in light sky blue is long term mean for 1984-2013 for (a) Renk, (b) Juba.*

4. SUMMARY AND CONCLUSIONS

Climate extremes including drought, floods, and high or low temperatures are recurrent in South Sudan and they are associated with many socio-economic miseries. This study aims at enhancing our understanding of past and present characteristics of climate extremes over South Sudan based on temporal patterns of the past rainfall and temperature extremes. The datasets used in this study were monthly rainfall and temperature for the period 1954 to 2013. Temperature records included both maximum and minimum values. Graphical methods and statistical techniques such as Mann Kendall statistics, Spectral analysis, Standardized Precipitation Index (SPI) and Gaussian kernel function were used to investigate the past and present characteristics of rainfall and temperature.

It was found that the rainfall over South Sudan is characterized by a uni-modal annual distribution with its peak in the months of July and August, with June through to August (JJA) being the main rainy season contributing to more than 50% of the total annual rainfall. The study found out that the highest maximum temperatures are usually recorded in the month of April while the lowest minimum temperature values occur in the months of December and January.

The trend analysis for the seasonal precipitation showed a general decline in the JJA seasonal rainfall at many locations, with both the maximum and minimum temperature indicating a significant increase in trends for all locations considered in the study at 0.05 significance level. There were however some seasonal differences in the patterns of the increasing trends.

The inter-annual patterns of rainfall indicated a recurrent pattern of floods and droughts over all locations in South Sudan. Two distinct spectral peaks of rainfall and temperature were common at all locations centered at 3-5 to 7-9 years. The Probability distribution function showed a shift of the entire distribution towards the dry climate conditions for rainfall and a warmer climate for maximum and minimum temperatures.

The findings of this study indicates a decline in rainfall, increasing temperature patterns, and a recurrence of climate extremes, which are key indicators of climate change signals over South Sudan. These findings can help policymakers to make informed decisions for mainstreaming climate related risks for sustainable development. Further work should be done to strengthen this findings by use of observed gridded dataset and projected future climate based on the Global Climate Model (GCMs) and Regional Climate Model (RCMs) outputs under different emission scenarios.

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