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Changes in Rainfall and Surface Temperature Over Lower Jubba, Somalia

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ABSTRACT

Climate is changing at an alarming rate threatening the critical pillars for environmental, social and economic development. Signals of climate change seems to be quite real for many African communities. Somalia, is one the countries of the GHA that has faced unique climate variability and climate change challenges, within severe conflict environment and lack of a stable government for many years. The objective of this study was to understand the past and present rainfall and temperature patterns over Lower Jubba. Rainfall data used extended from 1981-2015, while those of temperature 1981-2012. The study for rainfall concentrated within the two main rainfall seasons namely *Gu* and *Deyr.* Temperature data were however analysed for all the four seasons, June to August, December to February, September to November, and March to May. The data were subjected to various trend analysis methods that included time series plots of the graph of the specific rainfall and temperature observations. Two statistical approaches namely linear regression and Man-Kendal non-parametric statistics were employed in testing the significance of the slope of the rainfall and temperature time series for specific seasons. Evidences from tend analyses showed increasing trends in both minimum and maximum temperatures at all locations and all seasons, which is consistent with patterns that have been delineated in many parts of the Greater Horn of Africa. IPCC among many other past studies have linked global temperature increase worldwide to climate change induced global warming. Due to limitation in the length of temperature data used in this study, it be would be difficult to attribute the observed trends in temperature records entirely to climate change. The results from rainfall showed that most of the trends observed were not statistically significant. Few significant trends that were delineated at some locations were not spatially consistent over large areas. The most dominant characteristics of rainfall time series were high degree of interannual variability with recurrences in high/low value extremes that are often associated with floods/droughts. Some of these extremes occurred during El Nino /La Nina years. Results are consistent with those from some past studies in the region. The results from the study can be used in the planning and risk management of all climate sensitive socio-economic development activities in Somalia, especially in the development of strategy for sustainable community livelihoods and development in Lower Jubba.

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1. Introduction

The increase in global temperature due to anthropogenic causes has been stated with certainty by the Intergovernmental Panel on Climate Change (IPCC, 2014). The change in the climate system may already be affecting human health, including temperature related mortality and morbidity, with some of the health issues being due to the change in the ecology of infectious diseases (Patz, Epstein, Burke, & Balbus, 1996; WHO, 2003; Patz, Campbell-Lendrum, Holloway, & Foley, 2005; McMichael, Woodruff, & Hales, 2006; IPCC; 2007; 2012; 2014).

The African continent is highly vulnerable to the changing climate due to low adaptive capacity, and the recurrences of the climate related hazards (IPCC, 2014). The impacts of climate change globally are unevenly distributed with developing countries projected to face the greatest challenges (IPCC, 2007; 2014). Climate change impacts are projected to slow down economic growth, making poverty reduction more difficult, prolonging existing and creating new poverty traps in developing countries (IPCC 2014). The link between climate change and poverty poses a further threat to sustaining the gains made thus far.

Livelihoods in Somalia are characterised by low levels of income and dependence on risky pastoralism practices (Thurow, Herlocker, & Elmi , 2011). Frequent and recurring droughts in Somalia often disrupts economic activities (FGS, 2012). The UNEP reported droughts as being far more consequential to the society and development aspirations in Somalia than any external shocks (UNEP, 2005). Drought in Somalia killed approximately forty thousand people and affected 14 million people between 1900 and 2016, while aproximately 3500 people were killed and 3.5 million people affected by floods in the same period (The International Disaster Database, 2016).

This study was conducted in Somalia which has a land area of 637,540 km^2, and is situated within latitudes 1.5ºS – 12.0ºN and longitudes 41.0ºE – 51.0ºE. Somalia is part of the Greater Horn of Africa that also includes Ethiopia, Eritrea, Uganda, Sudan, South Sudan and Djibouti. Somalia is characterized by four seasons, two dry seasons from December to March (known as *Jiilaal*) and from July to September (*Xagga*). It also has two rainy seasons from April to June (*Gu*) and October to November (*Deyr*) which sometimes includes September (NAPA, 2013).

Rainfall in Somalia is generally low and erratic with the average annual rainfall being 250 mm with the exception of the south-west that receives 700mm annually. Rainfall in Somalia is affected mainly by the Inter-Tropical Convergence Zone (ITCZ), monsoonal winds and ocean currents, jet-streams including the 'Somali Jetstream', easterly waves, tropical cyclones, the Indian Ocean and Red Sea conditions, as well as teleconnections with various regional and global scale climate systems. The rainfall is further affected by Quasi-biennial Oscillation (QBO), El-Niño/Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and intra-seasonal waves (NAPA, 2013).

The mean surface temperature in most months and throughout the country is about 30ºC to 40ºC. Cooler temperatures are concentrated in the southern coastal regions and at higher elevations, as well as during the relatively cooler months of December to February. The highest seasonal temperature variability occur in the North when winter months bring below freezing temperatures to the highlands, and summer heats the Gulf of Aden coast up to more than 45ºC. The hottest period in the north is experienced in the months of June to September (IGAD, 2016).

Jubbaland lies 40–60 km east of the Jubba River, stretching from Gedo to the Indian Ocean, while western side lies in the North Eastern Province of Kenya. Jubbaland consists of the Gedo, Lower Jubba and Middle Jubba provinces. Kismayo located in Lower Jubba is its largest city, and the third largest city in Somalia after Mogadishu and Hargesa (AMISOM, 2016).

In this study we examine the spatial and temporal characteristics of past and present rainfall and surface temperature over the Lower Jubba of Somalia. Rainfall data used extended from 1981-2015, while those of temperature were from 1981-2012. Being the first State formed by the Federal Government of Somalia, successful implementation of climate change mitigation and adaptation strategies in Jubbaland would be a precedent for other emerging states to build upon. Details of the data used and methods adopted are discussed in Section 2.

2. Data and Methodology

2.1 Data Used

Inadequate observed climatic data is a challenge in the sub-Saharan region. Jubbaland State currently has no meteorological services. However the Food and Agriculture Organization (FAO) Somalia Water and Land Information Management (SWALIM) manage automatic weather stations in Afmadow (42.10, 0.50) and Bardheere (42.30, 2.35) where the data is recorded as aggregated monthly totals. The precipitation data from these two stations for the period 1981 to 2015 manned by SWALIM but shared with ICPAC were used in the study[1].

Additional rainfall data used in the study was the gridded observation/satellite blended Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset. Details on CHIRPS data and their usability in the region are well documented by ICPAC among many others (ICPAC, 2016; GeoCLIM, 2016). The CHIRPS data used in this study is a quasi-global rainfall dataset managed by the Climate Hazard Group that spans from 1981 to 2015 and incorporates 0.05° resolution satellite imagery (Climate Hazard Group, 2016). Precipitation data was analysed according to Somalia nationally characterised rainy seasons, the *Gu* long rain season from April to June, and the *Deyr* short rain season from September to November (NAPA, 2013).

Due to limitations in getting station observed data for Somalia, the study exclusively used the gridded 10-day (decadal) temperature data datasets from CHIRPS. Observed minimum, maximum and average temperature was investigated for all the standard global climatological seasons namely northern hemisphere summer, winter, autumn and spring seasons that correspond to June to August, December to February, September to November, March to May months. Data used was observed data from the Climate Hazard Group for the period between 1981 and 2012. The climate data sets were obtained from the ICPAC databank usually archived from National Meteorological and Hydrological Services (NMHSs) member countries (ICPAC, 2016).

2.2 Methodology

The rainfall analysis was done on the two standard Somali rainfall seasons *Gu* (April to June) and *Deyr* (September to November). Seasonal temperature time series were generated for all individual seasons namely June to August, December to February, September to November, March to May months and the results mapped. Climatological analysis was done on the rainfall and temperature data using GeoCLIM software. The software was used to calculate the seasonal mean and perform trend analysis for each pixel and the resulting raster files mapped to display the statistical characteristics of temperature and rainfall based on long-term time series of the data. The data from the seasonal mean was also extracted from the raster files and plotted to generate a time series. The rainfall and temperature time series were subjected to trend analyses as highlighted in the following section.

2.2.1 Trend Analysis

Trend represents long term movement of the time series and can be derived from graphical

[1] SWALIM datasets are not officially endorsed by the World Meteorological Organization (WMO)("Siting and Exposure of Meteorological Instruments," 1993; "Papers and Posters presented at the WMO Technical Conference on Instruments and Methods of Observation," 2008).

and statistical techniques allowing for a temporal and spatial approach. Both graphical and statistical techniques used in this study are similar to those that have been adopted in many studies in Africa and the world at large (Ogallo, 1979; 1980; 1981; 1982; 988; King'uyu, *et al.*, 2000; Omondi, et.al., 2009; IPCC, 2007; IPCC, 2012; 2014, Omay, *et al.*, 2016). The graphical method involves the plotting of the time series of the variables of interest. In this study both seasonal rainfall and temprature presented above were plotted. Such time series are ofted smoothed out in order to obtain natural trend of the center of mass of the data. The disadvantage of the graphical method is its dependency on visual judgment. The time series were subjected to a parametric and non-parametric statistical tests. The paramentric approach involved testing the statisticall significance of the slope of the temperature and rainfall time series. A linear regression trend was investigated by examining the relationship between time (T) and the variable of interest (Y), in this case rainfall and temperature parameter. The slope, indicates the average rate of change in the dependent variable in each year of the time period. A slope that statistically differs significantly from zero is a significant trend, while for lack of a trend, the slope is not significantly different from zero.

The most commonly used statistical methods non-parametric methods based on rank statistics such as Mann-Kendall and the Spearman rank tests (Ogallo, 1980; 1981; Muthama , et al., 2012). In Mann Kendall analysis, positive values indicate an increase in constituent with time, whereas negative values indicate a decrease in constituent with time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Rank Statistic. Data for performing the Mann-Kendall Analysis is done in time sequential order. The test compares the relative magnitudes of sample data rather than the data values themselves. Mann-Kendall Rank statistics is used for trend analysis as it makes very few underlying assumptions about the structure of the data. Details on this methods can be obtained from Kendall (Kendall, 1938; 1945; 1948). Significant trends form one of the key foundation of climate change detection.

GeoCLIM software was used to calculate a linear trend line for each pixel in the study area using a regression analysis of the seasonal totals. The results was obtained in raster format and shows the slope of the regression line. For the rainfall data, the results is given in mm of rain gained or lost per decade. The software also provides a raster showing the coefficient of determination (r2) of the regression as an indication of the consistency of the trend. The resulting rasters were mapped to deleinate the spatial patterns of the temperature and rainfall trends. Details of the results from the study are presented in section 3.

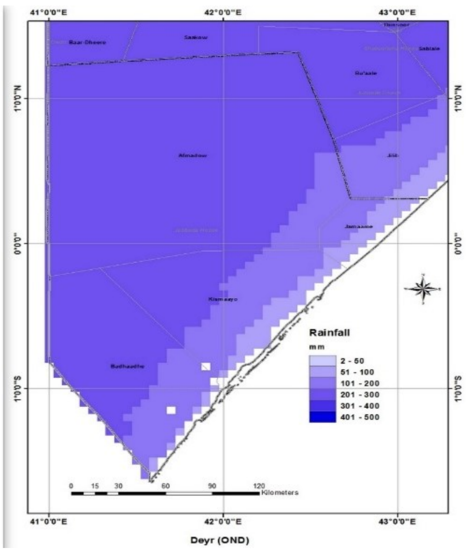
3. Results and Discussion

In this section, the results for rainfall and temperature are presented in separate sections

3.1 Results from Rainfall time series

Before the presentation of the observed rainfall and temperature trend observed from the study, some brief discussions of the mean rainfall characteristics for the *Gu* (AMJ) and *Deyr* (SON) seasons are provided. **Figure 1** shows representation of spatial patterns of the climatology of the rainfall for *Gu* (AMJ) and *Deyr* (SON) rainfall seasons, based on the available 1981-2015 data in Lower Jubba.

1(a)



1(b)

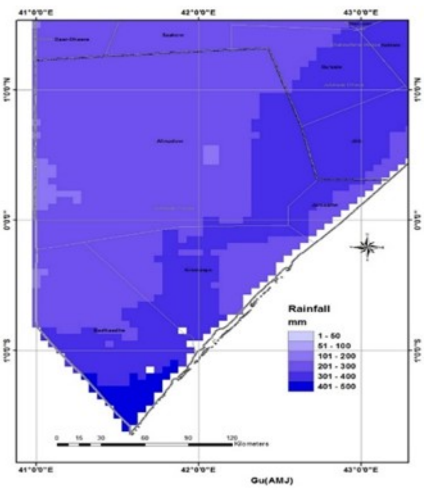


Figure 1: Map showing average *Gu* (Apr-Jun) (Figure 1a) and *Deyr* (Sep-Nov) (Figure 1b) rainfall seasons 1981-2015 in Lower Jubba (derived from ICPAC blended raw CHIRPS and station data)

The mean seasonal rainfall agrees with results that show that Lower Jubba is one of the places with high amounts of seasonal rainfall in Somalia (NAPA, 2013). It receives relatively more rainfall during *Gu* (about 350mm) compared to *Deyr* (average 250mm) season. However, the latter season is more spatially homogeneous than the former. This is consistent with previous studies on Somalia that show the average rainfall during the Gu season in Lower Jubba to be 300mm and 200 mm during the *Deyr* season (Muchiri , 2007; NAPA, 2013). Average rainfall received in both seasons per district is displayed in **Table 1**.

Lower Jubba receives about the same amount of rainfall during the September to November season as the OND season in bordering counties of Garrisa, Wajir and Mandera in Kenya, which average 110 to 200mm of rainfall in that season (Muita, 2013). **Figure 1** further shows that the southern coastal band receives the highest precipitation compared to other areas in *Gu* season while the coastal area is drier compared to other parts of the study area during the *Deyr* season. Parts of the Western/North Western regions receive the highest amount of rainfall in Lower Jubba during the *Deyr* season but receive the lowest amount of rainfall during the *Gu* season. **Table 1** gives the Seasonal Rainfall lowest/highest values at four locations in Lower Jubba. The large seasonal variability in the range between maximum/minimum values is common at all locations.

Table 1: Seasonal Rainfall Minimum/Maximum values in Lower Jubba

District	*Gu* (*Rainfall mm*)		*Deyr* (*Rainfall mm*)	
	Min	**Max**	**Min**	**Max**
Badhaadhe	197	486	94	273
Afmadow	188	363	134	277
Jamaame	271	352	69	141
Kismaayo	233	339	61	244

Figure 2(a & b) gives both smoothed and unsmoothed *Gu* season rainfall time series for Lower Jubba. A general decreasing trend in rainfall is quite evident. This is consistent with some studies on the Greater Horn of Africa that have shown a persistent decline in rainfall during the March-April-May (MAM) "long rains" season (Tierney, et al., 2015). Similar studies over the counties bordering Lower Jubba in the North Eastern parts of Kenyan also show a reduction in the "long rain" season (Lyon & DeWitt, 2012). Recurring failures in seasonal rainfall in the recent past has aggravated severe drought over the study area (Lyon & DeWitt, 2012; Connolly-Boutin & Smit, 2016). Sample results from statistical tests are given in **Table 2**.

The results show a general decrease of rainfall during *Gu* season at all location with an increasing trend in rainfall during the *Deyr* "short rain" season. This is consistent with studies on the region that have shown an increase in the OND rainfall in the North Eastern parts of Kenya bordering Lower Jubba (Lyon & DeWitt, 2012; Lyon, 2014). The short rains are important in maintaining the grasslands and shrublands, and its deficit creates unfavourable conditions for grazing, crops growth and development (Indeje, et al., 2000). The short and long rains in Somalia, like in the Horn of Africa region are as a result of the seasonal shifts in the Inter-Tropical Convergence Zone (ITCZ) (Indeje, et al., 2000; NAPA, 2013).

The trend lines for both Gu and Deyr seasons are statistically insignificant at a significance level of 0.05 (p = 0.08 Gu, 0.22 Deyr).

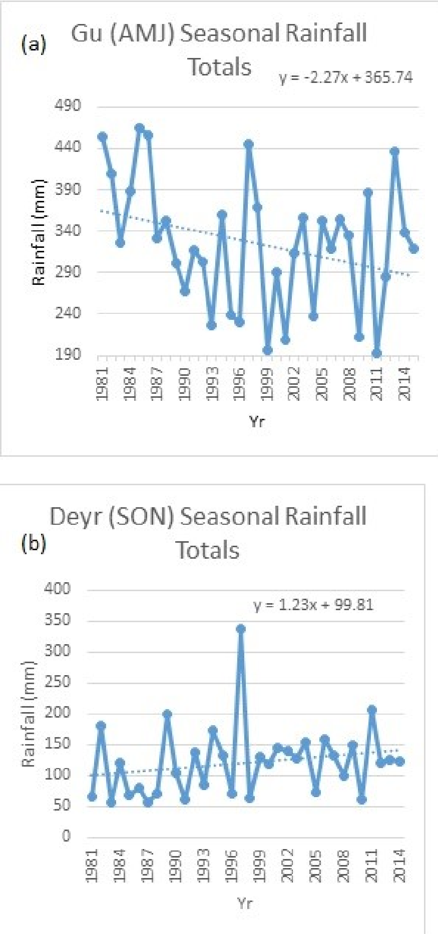


Figure 2: Graphs showing the mean inter-annual rainfall variability during the *Gu* (1a) and *Deyr* (1b) season between the years 1981 and 2015

Figures 3(a & b) show the spatial distribution of the changing trends in the seasonal rainfall over Lower Jubba for *Gu* and *Deyr* seasons between 1981-2015. **Figure 3b** shows that all areas in Lower Jubba experienced a general but non-statistically significant increasing trend in the Deyr season. **Figure 3a** shows that for *Gu,* some parts of Lower Jubba experienced a decreasing but not-statistically significant trend. Few areas experienced an increasing but non-significant trend in the *Gu* season. Although the rainfall trends were not statistically significant, the complexity of the observed characteristics of the changes implies a need in the investment in a tailor-made climate risk management as well as climate change mitigation and adaptation strategies for each district. Details of the pattern in the trend in each district can be seen in **Table 2**.

Table 2: Summary of Rainfall Trends in Lower Jubba

District	***Gu (Rainfall Trend mm/ decade)***		***Deyr ((Rainfall Trend mm/decade)***	
	Min	**Max**	**Min**	**Max**
Badhaadhe	-35	15	11	42
Afmadow	-14	14	12	48
Jamaame	-26	-2	8	18
Kismaayo	-3	19	8	36

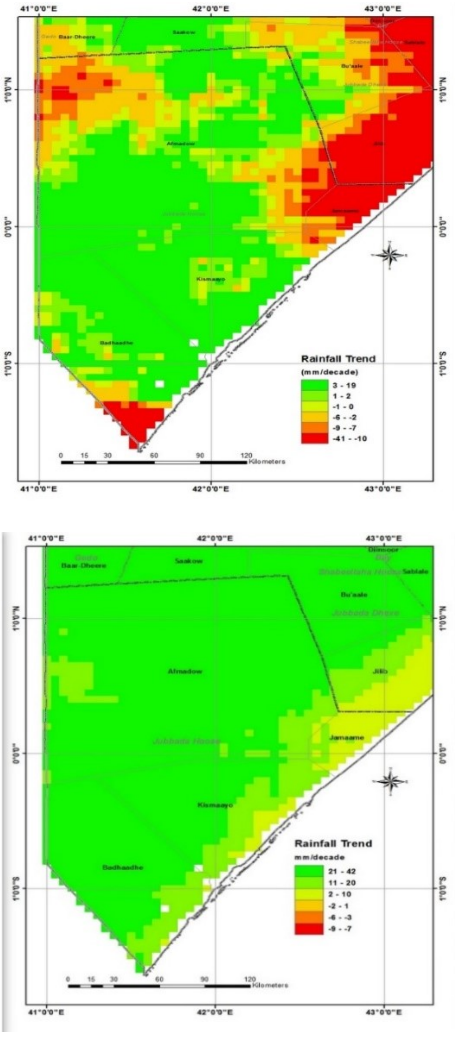


Figure ~~3~~3: Map showing Average rainfall Trend 1981-2015 during *Gu* (3a) and Deyr (3b) rainfall season in Lower Jubba (derived from ICPAC)

Persistent and recurrent drought as well as long-term trends in climate have been associated with the likelihood of civil conflict as natural resources become limited (Barnett & Adger, 2007; Hendrix & Glaser, 2007; Maystadt & Ecker, 2014). For a region that is heavily reliant on pastoralism, whose movements are dependent on the search of pasture and water, migration from areas of Lower Jubba experiencing negative trend in rainfall to areas experiencing increase in rainfall is common. Such movements are common drivers of conflict amongst pastoralists in the struggle for limited pasture and water. The observed increasing trend in rainfall in some areas and a decreasing trend in other areas will impact human security, climate change adaptation and sustainable development in Lower Jubba. This highlights the need for tailor made interventions for different regions each specific to related priorities.

Figure 4 shows the rainfall anomaly computed relative to 1981-2015 for the *Gu* seasons. Examining the long rain season (*Gu*), Lower Jubba shows an increase in occurrence of depressed rainfall usually associated with drought. The number of above normal rainfall associated with floods decreased in frequency during the study period. This highlights the general negative rainfall trend during the *Gu* season seen in **Figure 2**, even though this trend is not statistically insignificant, and further supports studies showing the decrease of March-May long rains in the GHA region (Schreck & Semazzi, 2004; P. A. Omondi, et al., 2009; 2013).

The ENSO phenomenon has been linked to some rainfall anomalies in the Horn of Africa, with catastrophic disruption of socio-economic infrastructure and loss of life (Ogallo, 1988; Indeje, et al., 2000; Schreck & Semazzi, 2004; Bowden & Semazzi 2007; P. A. Omondi, et al., 2013). The enhanced rainfall peaks were seen in the Deyr season in 1997 and coincides with the floods reported for Somalia by the international disaster database that affected 1,230,000 and killed 2,311 people ("EM-DAT," 2016) and has been linked to the simultaneous strong El Niño-Southern Oscillation (ENSO) event of 1997–98.

Some of the below normal rainfall in the **Figure 4** also overlaps with the reported droughts in Jubbaland (The International Disaster Database, 2016). The primary sources of climate variability over the Horn of Africa is the ENSO and Indian Ocean Dipole (IOD) through the Sea Surface Temperature (SST) variations in the Indian Ocean, while an isolated secondary but significant pattern is based on seasonal (OND) rainfall data (Ogallo, 1988; Schreck & Semazzi, 2004; Bowden & Semazzi 2007; IPCC, 2007; Lyon, 2014). Droughts reported for Somalia in 1987, 1998, 2008-09, 2010, 2011/12 and 2016/17 all coincided with La Niña phenomenon in the same years (The International Disaster Database, 2016).

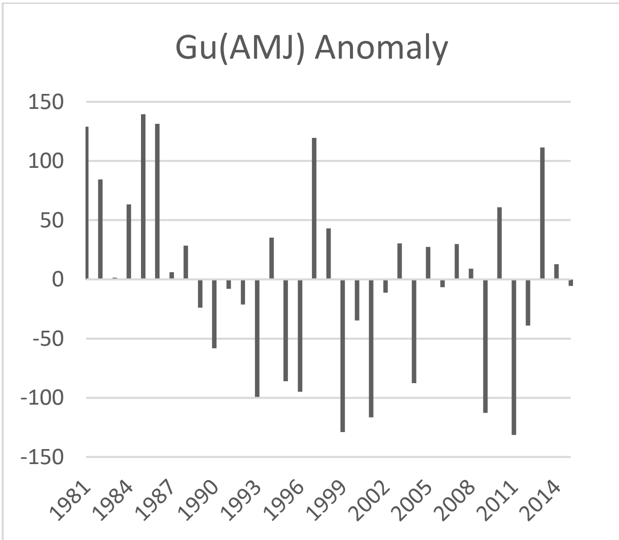


Figure 4: Graph showing the rainfall anomaly during the Gu rainfall season between 1981 and 2015 (Relative to 1981-2010)

3.2 Past and Present Changes in Temperature

Figure 5 gives the mean annual cycle in the average minimum, maximum and average temperature for the between 1981 and 2012.

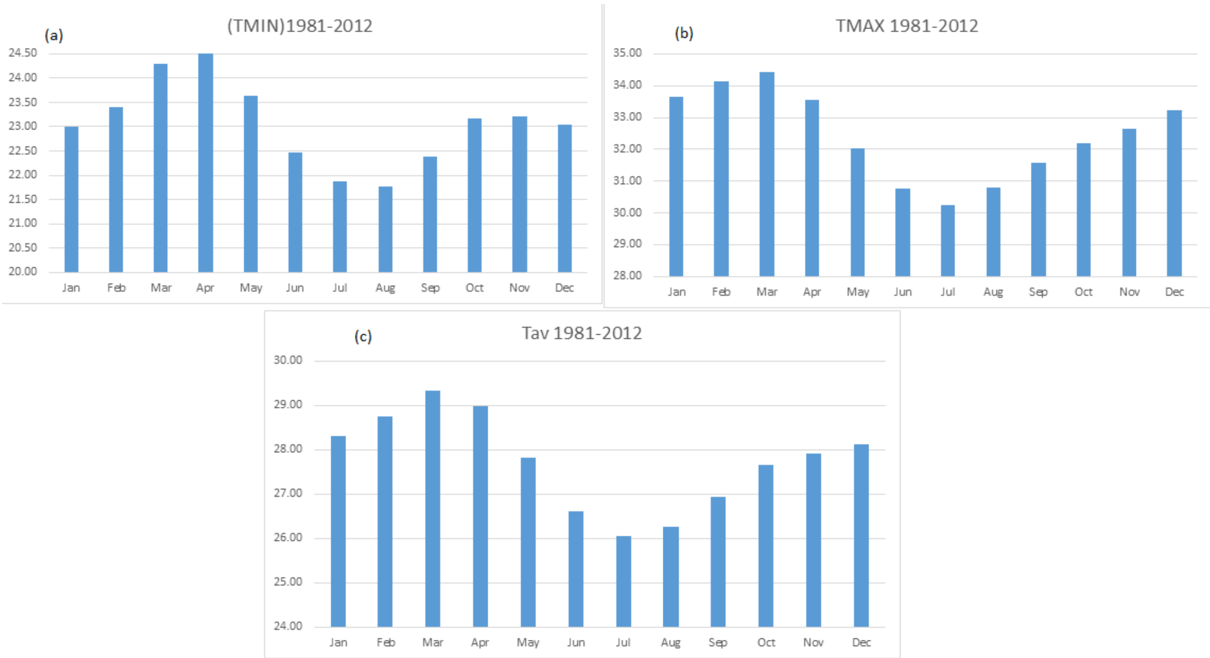


Figure 5: Annual temperature cycle in the (a) minimum (Tmin), (b) maximum (Tmax) and (c) average (Tav) temperature between 1981 and 2012

From the minimum temperature in **Figure 5(a)**, July and August are the coldest months while March and April have the highest minimum temperature. The recorded temperatures are relatively high in February and May as well. From the maximum temperature in **Figure 5(b)**, Jun and July shows the coldest months while February and March records the highest maximum temperature. Overall as seen in **Figure 5(c)** June, July and August record the lowest temperatures while March records the highest maximum temperature. February, Jan and April also recorded high temperature values overall. The distribution of the mean temperature is quite similar to what is observed in the maximum, and the minimum temperature.

Figure 6 looks at the spatial distribution of the average temperature in the seasons DJF, MAM, JJA and SON in the years 1981-2012 from the satellite data by the Climate Hazard Group. The variation of temperature in different locations in Lower Jubba for the four standard seasons are shown in **Figure 6**. Overall, the average minimum temperature seems to increase towards the southern costal band while the average maximum temperature increases northwards. This could be due to a correlation between sea surface temperature from the Indian Ocean and surface air temperature (A. K. Jaswal, et al., 2012). The map also shows JJA as the coldest of the four seasons.

Figure 7 shows a time series on the average temperature in Lower Jubba from 1981 to 2012 in the DJF, MAM, JJA and SON seasons. The results show in **Figure 7** shows a positive trend in the average temperature in all seasons. Studies have shown an increasing trend in temperature at a global and regional level (King'uyu, Ogallo, & Anyamba, 2000; Easterling, et al., 2009; IPCC, 2014). Results also correlate with studies on the Horn of Africa region that shows an increase in temperature (King'uyu, et al., 2000). All the results are statistically significant at a significance level of 0.05 (p=0.04 for each graph).

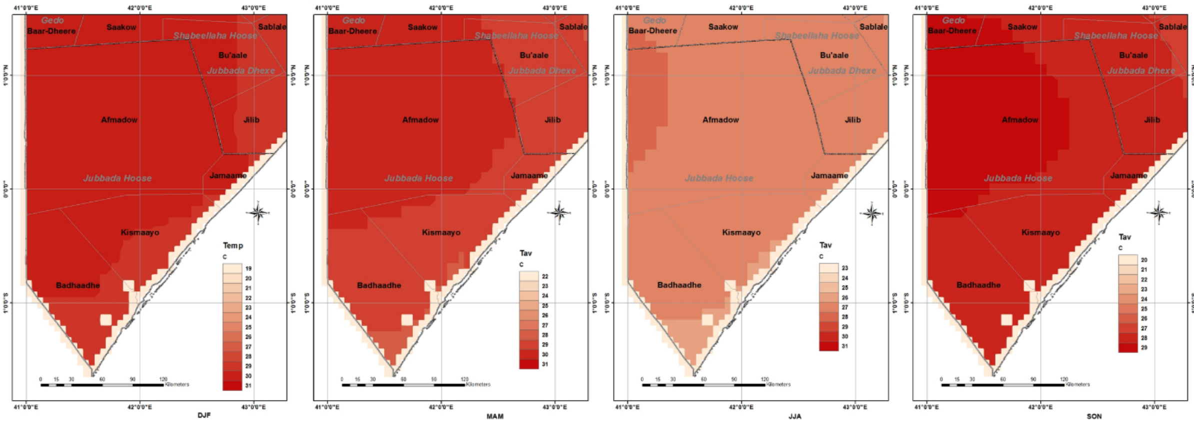


Figure 6: Map showing the spatial distribution of average (Tav) temperature in the DJF, MAM, JJA, and SON Season (1960 to 2012)

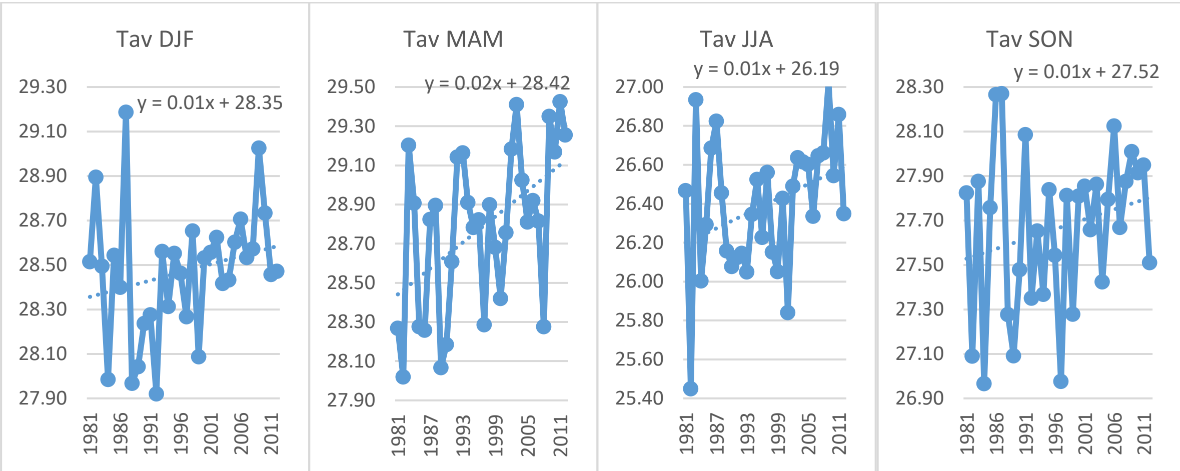


Figure 7: Time-series plot of the average seasonal average (Tav) temperature in the DJF, MAM, JJA, and SON Season (1981 to 2012)

Figure 8 shows a spatial distribution in the changes in temperature. A positive trend in the change in temperature is observed in the entire region through the spatial distribution of this trend varies from season to season. Although the changes in temperature trends are consistent with those that have been observed over parts of the region and the rest of the world that have been linked to global warming related climate changes, the limitations in our data makes it difficult for us to attribute the observed temperatures trend directly to climate change. Increase in temperature could change the ecology of infectious diseases as well as increase temperature related mortality and morbidity of people and livestock (Jonathan A. Patz, et al., 1996; WMO, 2003; IPCC, 2014c).

Figure 9 shows the anomalies observed in the average temperatures. The recurrence of below normal and above normal extremes persists though some are very large. It should be noted from **Figure 9** that the inter-annual variability in the patterns of extreme minimum and maximum temperatures that were observed in rainfall were also discernible in the temperature patterns with recurrences on the extremes in minimum and maximum temperatures.

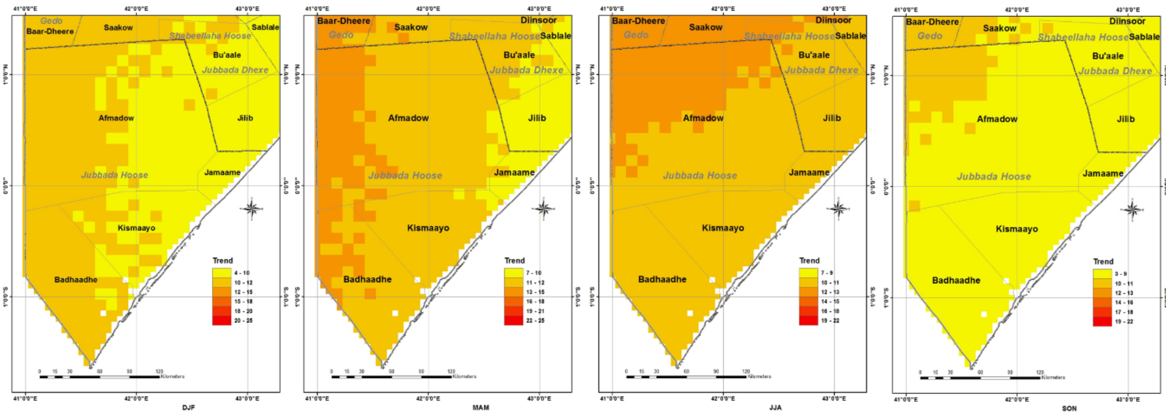


Figure 8: Spatial distribution of the trends in and average (Tav) temperature in the DJF, MAM, JJA, and SON Season (1981 to 2012

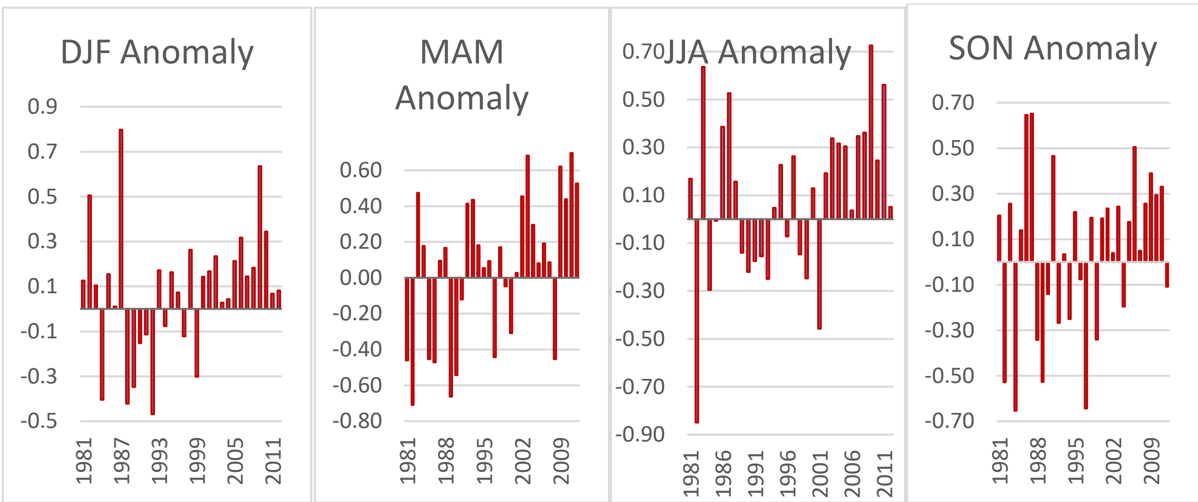


Figure 9: Anomalies in temperature during minimum (Tmin), maximum (Tmax) and average (Tav) temperature in the DJF, MAM, JJA, and SON Season (1981 to 2012

Conclusions

In this study, we examined spatial and temporal characteristics of past and present precipitation and surface temperature over the Lower Jubba of Somalia. The results from analyses revealed a high degree of inter-annual variability with recurrences in high/low value extremes that are often associated with floods/droughts. Some of these occurred during the El Niño/ La Niña years. The study further showed general increase in occurrence of depressed rainfall usually associated with drought. It showed above normal seasons associated with floods decreased in frequency during the study period. A general decrease in OND during the *Gu* season was also seen, with a general increase in during the Deyr season. Most of the rainfall trends we however not statistically significant.

Results are however similar to regional studies that show a similar change in the long rains and short rains over time that are very likely due to climate change (Schreck & Semazzi, 2004; P. A. Omondi, et al., 2009; Philip Amingo Omondi, et al., 2013; IPCC, 2014). Studies in the GHA region have shown that climate related extremes have been the dominant trigger of natural disasters including Somalia (Omondi, et al., 2013). The region has witnessed frequent episodes of both excessive and deficient rainfall (Ogallo, 1979; Ogallo, 1980; Ogallo, 1981; Ogallo, 1982; Omondi, *et al.*, 2013; Mwangi *et al.*, 2014; Omay, *et al.*, 2016).

The temperature results indicated increasing trends in the minimum, maximum and average temperature at all locations and seasons. These are consistent with the results from many recent studies worldwide (King'uyu, et al., 2000, Easterling, et al., 2009; IPCC, 2014). Thus, it may be concluded from temperature analyses that like the global observation, both minimum and maximum temperatures are observed to increase in all seasons in Lower Jubba. Like in the case of rainfall time series, there were also evidences of recurrences of extreme high/low values in the interannually patterns of both max/min temperatures. Some of the high/low temperature values observed during the period of low/high rainfall linked to El Niño/ La Niña and anomalies in other regional rainfall systems. Due to limited data however, it was also difficult to link the observed temperature changes in Lower Jubba wholly to climate change. Increase in temperature could also change the ecology of infectious diseases as well as increase temperature related mortality and morbidity of people and livestock (Jonathan A. Patz, et al., 1996; WMO, 2003; IPCC, 2014c). Many worldwide changes in max/min temperatures have been linked to climate change induced global warning. These results for the first time provide more insight knowledge regarding climate variability and change, and the development of climate smart strategies for Somalia, especially for Lower Jubba region in support of sustainable livelihoods, and the general planning and management of all socio-economic systems.

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