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Evidencing Local Climate Change and its Implications for Subsistence Agriculture Planning in Huambo Province Angola, Southern Africa

Paulo M. Kiala[a*], Ian A. Simpson[b]

[a]*Faculty of Agricultural Sciences (FCA) of the José Eduardo dos Santos University (UJES), Chianga, Huambo, Angola*
[b]*Biological and Environmental Sciences, University of Stirling, Stirling FK9 4LA, Scotland, UK*
[a]*Email: pmakiala1@gmail.com,* [b]*Email: 4b101ias@gmail.com*

Abstract

Intensifying climate change is becoming increasingly apparent in Southern Africa with modified precipitation patterns and increases in temperature affecting growing seasons, agricultural production and food security for small-scale farmers. While there is a strong commitment from agricultural extension services to plan the management of climate change impacts in the region, these endeavours are hampered by a lack of knowledge on how climate scenarios will develop at a scale relevant to local communities. In this paper, we construct new scenarios for climate change in Huambo province, Angola, based on colonial and postcolonial local climate data sets. In so doing we highlight the role that this type of archived – physical - data can have in constructing future climate scenarios and which can form a foundation for local land evaluations and community adaptations.

Our case study is the province of Huambo in Angola, particularly sensitive to climate change with a rainy and dry season, and with over 85% subsistence farming is typical of many areas of the region. The climate data sets used run from 1960 to the present day and include temperature, rainfall and evapotranspiration.

Trend detection, climatic variability and temperature and precipitation projection were determined by the statistical reduction methods using regression, correlation and time series analysis; statistical prediction methods included integrated autoregression models and moving average (ARIMA).

Our findings suggest a continuing increase in temperature, decline in rainfall, increase in the length of the dry season, and reduction in the number of rainy days, the impact of which will vary with soil water holding capacity and agricultural land management mitigation measures.

Keywords: Local Climate Change; Subsistence Farming.

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* Corresponding author.

1. Introduction

The Southern African region approximates from the parallels 06’00° S at its northern extent to the southernmost part of the continent at 35’00° S. This vast area covers climatic regimes ranging from tropical humid, subtropical, arid and semi-arid. Intensifying climate change is now evidenced in the region with changes in precipitation patterns, reductions in rainfall and temperature extremes [1] that are severely affecting agricultural practices and production in Southern Africa leading to food insecurity [2, 3, 4, 5, 6].

In Angola subsistence agricultural production is dependent on climatic conditions based on a single rainy season and is susceptible to drought characterised by crop failure, hunger and conflicts over water [7]. Subsistence farming in the region is a traditionally productive model integrating socioeconomic, cultural and environmental organization in which agricultural activities are developed by the family as a labor force to support their essential needs. The agricultural season usually starts between September and December through to May across most of the national territory on an average of 1.4 to 2.0 ha per household, often with two or more land units. However, subsistence farming generally gives low yields and is often insufficient for family requirements; furthermore, there is no surplus for commercialization and trade. Climate change influencing temperature and precipitation together with associated soil water holding capacity limitations are now accentuating these issues [8, 9].

To address these issues there is now an increasing drive toward a better understanding of past and future trends in climate change, including rainfall, temperature and weather extremes, and their potential impact on food production in Southern Africa subsistence farming [10, 11, 12, 13, 14]. As foundations for these analyses, international cooperation through the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) initiative has sought to provide consistent and reliable climate data for Southern Africa. This has involved commencing compilation, digitization and archiving of historical and current meteorological data for Angola [15, 16]. Efforts are also being made to implement strategies to manage climate change related risks and enhance adaptive capacity at a local level and in Angola it is necessary to identify the different factors that characterize sensitivity and capacity of rural communities to deal with the impact of drought [17, 18]. However, drought-sensitive rural communities in Angola are connected to their environment in complex ways and require comprehensive drought risk analyses to combine drought-relevant indicators for precipitation, evapotranspiration, soil moisture, and vegetation conditions. These factors combined facilitate the identification of areas exposed to multiple drought risk characteristics with monitoring required to assess sensitivity of families vulnerable to water scarcity and drought, particularly where rural populations are growing [19]. However, the continuing lack of information and monitoring of climate change at local scales relevant to local communities is limiting sustainable planning of mitigation measures [20, 21]. This is now being recognized in Angola where there are particular concerns over the future of subsistence agriculture on which approximately 80% of the population are dependent.

Within these contexts, the purpose of our paper is to construct scenarios of climate change – temperature and precipitation – local to Huambo province, Angola. These analyses are based on historical colonial and postcolonial climate data sets from between 1960 and 2017 together with statistically modeled projections from these data. In so doing we highlight what analyses is possible from these archived data and the prospects they hold for constructing future climate scenarios. The analyses are also considered as a foundation for local land evaluations and community adaptations. Our objectives are to:

- identify changes in annual average temperature, annual maximum and minimum temperatures
- identify changes in precipitation patterns including average annual precipitation and changes to the rainy season period
- make forward projections of temperature and precipitation change for the Huambo region

It is anticipated that these analyses will help realize future planning for sustainable land use by local agricultural extension services in Angola and translate into mitigating actions for family farming and small farmer producers in a climate-changed future.

2. Methods

2.1. Study location

The study was conducted in the province of Huambo, located in the central plateau of Angola, 1700 meters above sea level (Figure 1). The selection of Huambo province as a study area is due to its importance in agricultural production within Angola. It is the second province by population density in Angola, with more than 50% of the population dedicated to agricultural production. Over 85% of this is subsistence agriculture practiced on Ferralsols of limited water-holding capacity even though there is good rooting depth and with the use of rudimentary production technologies. Huambo is located in the tropical climate zone and has two main seasons per year, the rainy season and the dry (or winter) season. The rainy season generally has an average of 8 months, with the possibility of rain starting in September and ending in mid-May. The average annual precipitation is estimated to range from 1200 mm to 1500 mm. while the average annual temperature is estimated between 22°C and 24°C. The choice of the Angolan central highlands zone for this first local study of climate change in Angola is a starting point that will lead a more detailed evaluation of agricultural land capacities integrating soil water holding capacities and land management practices in relation to climate futures.

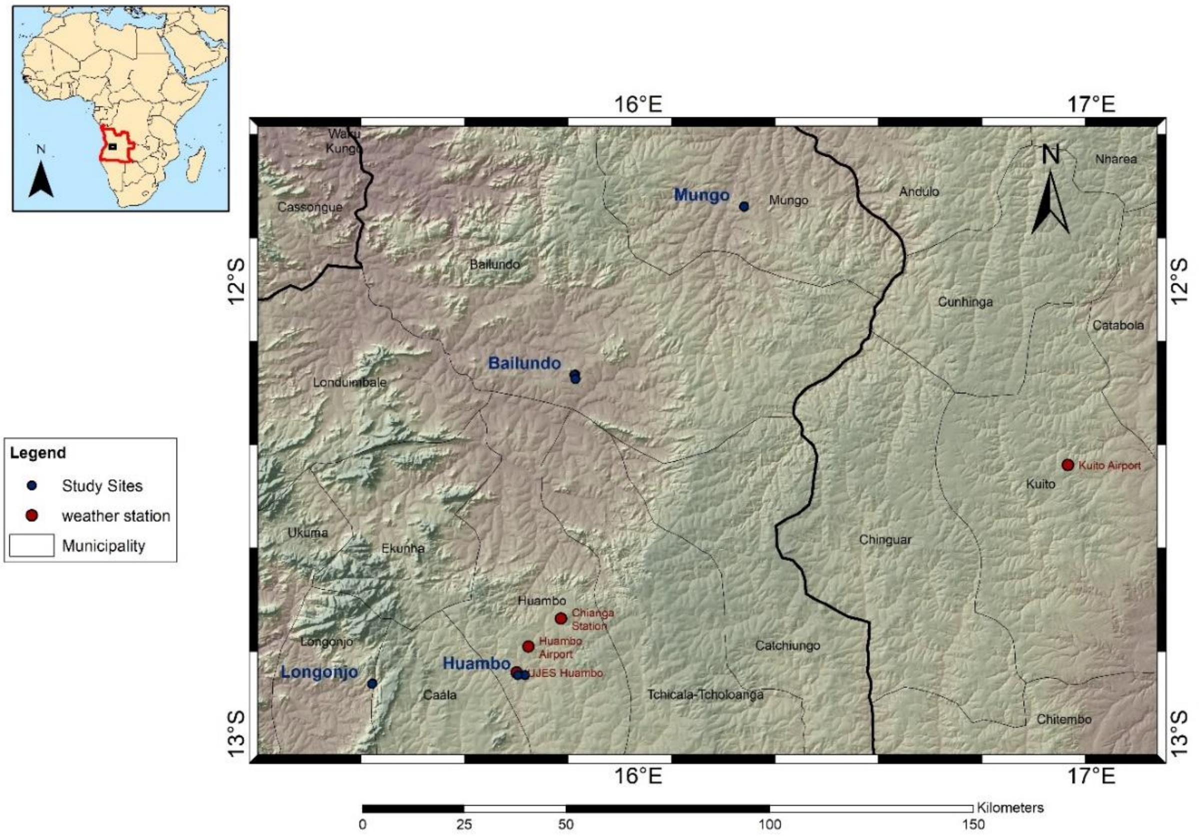

Figure 1: Study localities and weather stations in the region, of Huambo Angola.

2.2. Climate data sets

The primary climatic data set is provided by the conventional meteorological station of the Institute of Agricultural Research of Angola (IIA), located in the city of Huambo, village of Chianga, (latitude -12^{o}74'349", longitude 15^{o}82'923", 1690 meters above sea level). It is a daily historical data set and covers the period from the year 1960 to 2017. The station is the oldest in the region and is the only one that contains well-preserved historical data over more than 60 years and with more than 95% of the data being archived.

Data access was not straightforward; data was recorded during the colonial period (up to 1975), the post-colonial period, and the civil war (1975-2002), and the formats and forms of registration are not always the same. Furthermore, the data is in a manual form rather than digital or computerized. For this study, all the original data were re-recorded in pre-prepared tables that give daily recordings of minimum and maximum temperature, precipitation, and evaporation. These data were transposed into XL spreadsheets for analysis.

The Chianga data was cross-checked against the shorter and less complete data set from the nearby meteorological station located at Huambo airport (latitude -12^{o}48'00", longitude 15^{o}45'00", altitude 1700 meters asl) and at Kuito airport (latitude -12°24′15″, longitude 16°56′55″, altitude 1712 meters asl). Non-parametric statistical positive Pearson Correlation between Chianga and Huambo Airport 71.3%, 0.01) and Kuito Airport 80.8%, 0.01) and between the two airports with 63.3% (level of significance 0.01) were observed. With its nearto-complete data and statistically representative characteristics, the Chianga data set has been used in the subsequent analyses.

For temperature data (°C) the averages of the minimum and maximum monthly temperatures for 1960-2017 were calculated and annual mean temperatures was estimated using the formula to calculate the arithmetic mean:

$$(T_{mea} = \frac{\boldsymbol{Tmax+Tmin}}{\mathbf{2}})$$

(Annual Mean temperature (T_{mean}); maximum temperature (T_{max}) and Minimum temperature (T_{min})

For the evaluation of precipitation data, the total monthly values were used. The annual value was determined by the sum of the total precipitation values of each month during the year.

2.3. Statistical analyses of climate parameter predictions and relationships

Assessment of climate change and forecasting models are useful tools for risk management when considering climate instability. Non-parametric correlation and regression statistical tools were used to evaluate the trend of the time series and the relationship between climatic factors over a period of time (1960-2017). The annual temperature and precipitation data were normalized to calculate the Correlation Coefficient (CC) and to examine linear relationship between precipitation and temperature variability. The correlation coefficient (CC) was used to show the degree of dispersion between precipitation variability and temperature anomalies, which are statistically calculated at a significance level of 0.05 ($p < 0.05$) using SPSS tools.

Trend detection, climatic variability, and temperature and precipitation projections were determined by the Statistical Reduction method using regression, correlation and time series analysis within SPSS tools. Statistical prediction methods, integrated autoregression models and moving average (ARIMA) were also applied. Typically, these models are appropriate in annual and short-term predictions from existing historical data allowing the identification, modelling and extrapolation of patterns found in the data over time. To obtain reliable results within the acceptability range best fit models were determined. Different models were tested taking into account the autocorrelation function (ACF) and the partial autocorrelation function (PACF) of the differentiated data. For both models, temperature and precipitation were considered with p and q in the range of zero to two (0:2). As a result, the following models with 95% significance ($P<0.05$) were tested: (0,1,1), (1,1,0), (1,1,1), (1,2, 1), (1.2,1), (1,2,2), (2, 1, 0) and (2,1,1) . The model with the lowest value of ACF and PACF that best fitted the data was defined and selected for both temperature and precipitation. We recognise constraints in the structuring of meteorological data. They presented different annotation modes in recording, lacked a common format between and within the same meteorological stations and do not indicate the time they were recorded. Data were also recorded manually which presented some inconsistencies in the storage of meteorological data over time. These data elements may have influenced analytical outcomes, both positively and negatively, and which could not be identified or perceived. Nevertheless, we consider the trend data to be robust.

3. Results and Discussion

3.1. Analyses of annual temperature data, 1960-2017

Average maximum temperature. Maximum average temperatures of 1960, 1979, 1980, 2015 and 2017 were above the general average of the period (Figure 2), with a positive standard deviation of + 1.36 ° C, + 1.22 ° C, + 2.14 ° C, + 1.29 ° C and + 3.64 ° C, respectively. These years are considered the hottest throughout this study period. These high temperatures may be associated with the Southern Oscillation (El Niño ENSO) occurring at these time and particularly 2017 time [22]. These warmer temperatures correspond to the global climate model predictions developed by the Canadian Climate Centre, (CCC); Laboratory of Geophysical Fluid Dynamics (GFDL); and the United Kingdom Meteorological Office (UKMO), in conjunction with the IPCC [23] that suggest a 2 °C to 4 °C increase during the hot season across the subcontinent. (Figure 2).

Average minimum temperature. The highest values in relation to the mean for the minimum temperature of the period were recorded in 2016, 14.06ºC (Figure 2) with a positive standard deviation of +2.46ºC. 1980 is the lowest annual average minimum temperature, 8.54ºC with negative standard deviation of -3.05ºC. Between the years 1960 and 1981 the mean annual minimum temperatures were lower than 11.59 °C, the minimum estimated average of the study period. From 1982 to 2016, the data presents a positive standard deviation, above the average estimated for the entire period, except 2017 which has a negative standard deviation of -0.63°C. These year on year changes indicate that the annual average minimum temperature increases in a similar manner reported by Hulme and colleagues and Niang and colleagues [24, 25] for the region as a whole, indicating air surface temperature increases of 0.5 C in the last 50 years across most of Africa and supporting the argument that minimum (winter) temperatures are increasing faster than maximum (summer) temperatures [26].

Annual average temperature. During the 1960 – 2017 period there has been persistent increase in average temperatures over time (Figure 2 and Figure 3). From 1960 to 1986, the mean temperature records were below the general annual average temperature estimated for the period with the exception of 1981 and 1982. For the years 2010, 2015, 2016 and 2017 the annual average temperatures were above the 19.29ºC average for the period. These are the warmest years with deviations of +1.07ºC, +1.21ºC, +1.18ºC and +1.50ºC, respectively. 2017 was the year that recorded the highest average temperature in relation to other years with an average of 20.79ºC. The statistical results obtained in the study, as shown in Figure 3, confirm the relationship between temperature and time, with gradual increase in mean temperature and a positive significant difference ($p < 0.05$), (r^2 0.7535); 75% of the temperature variability is explained by the linear relationship with the time series. Zhou and colleagues and Kruger and Sekele [27, 28] have identified similar relationships indicating that the Southern Africa region has experienced an increase in mean temperatures during the second half of the twentieth century with the most significant warming occurring in the last two decades. We suggest that this is already having a locally observable negative influence on crop production through enhanced evapotranspiration and reduced water storage in the rooting zone [29].

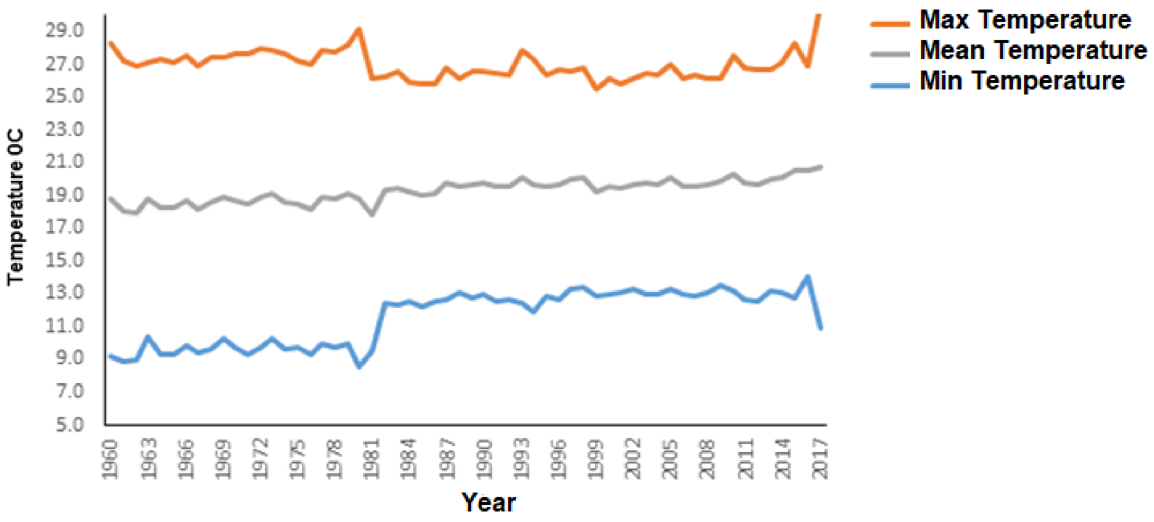

Figure 2: Inter-annual variability of mean minimum, maximum and annual average temperatures, Chianga – Huambo 1960-2017 climate data set, Huambo.

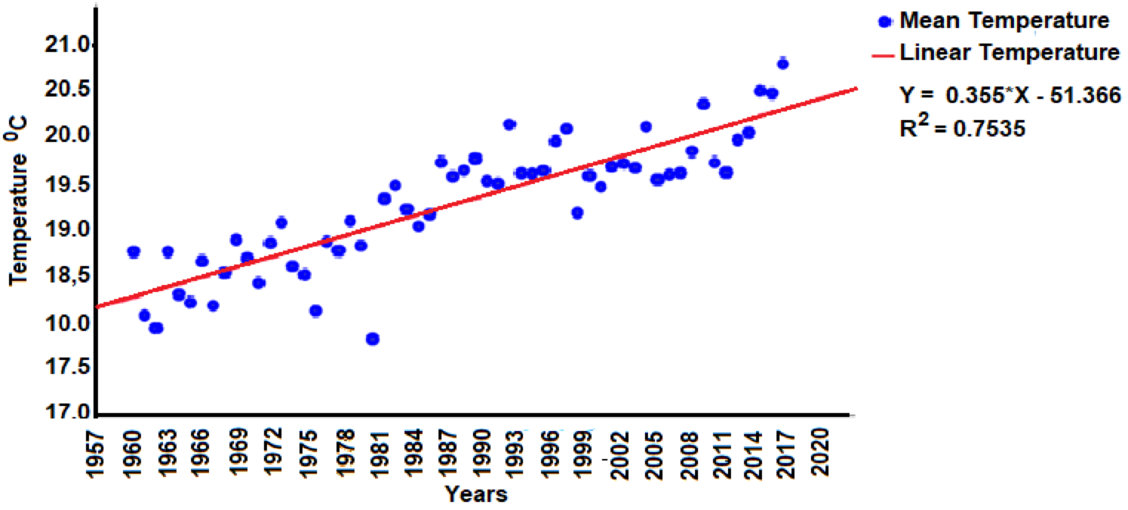

Figure 3: Inter-annual mean temperature variability over time, Chianga – Huambo 1960-2017 climate data set, Huambo.

3.2 Year on year variability

The temperature variability between the years represented in figure 4 shows the fluctuations in the temperature behavior that occurred over time. In this case, 1960 was considered, being the first year of the analyzed data. Therefore, the temperature of this year was considered as zero year, after which the comparison between the years began. In this case, the values with a negative sign indicate that in the previous year the average temperature was higher than that of the following year. Thus, the years 1981 and 1982 with the greatest difference in degrees over the study period with values of 1 ° C and 1.5 ° C, respectively. In general, the average temperature variability year by year is 0.33 ° C.

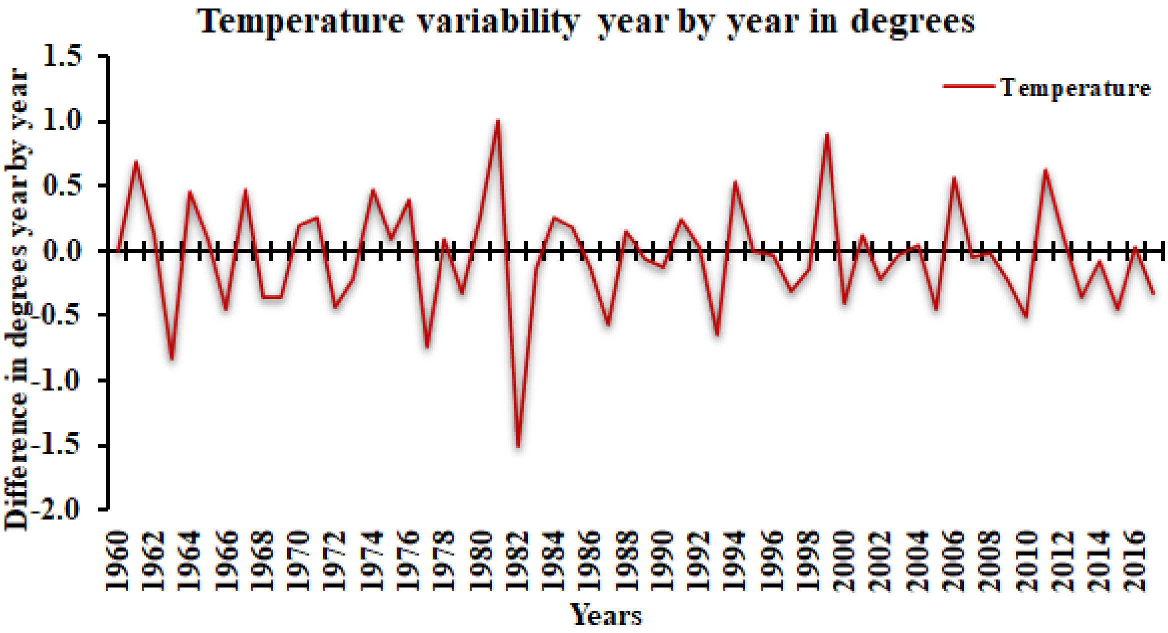

Figure 4: Year on year temperature fluctuation over studied period in Huambo province, Angola.

3.3. Analyses of precipitation data

Analysis of annual precipitation and rain days, 1960 to 2017. Characterising temporal changes in precipitation is essential to plan future water resources for substance farming systems that are entirely based on rainwater (Yan and Bai, 201[30] . Figure 5 shows annual precipitation for the Chianga – Huambo province data set from 1960 to 2017. The wettest year of this period was 1961with precipitation of 2813.13 mm and +1462.46 mm greater than the 1350.64 mm mean for the study period. This is however such a major outlier in the distribution that care is needed in its interpretation. The lowest annual precipitation is observed in the years 1998, 1989, 2007, 2008, 2010 and 2017, -523.44 mm, -482.14 mm, -424.54 mm, -502.44 mm, 413.64 mm and -534.34 mm, respectively lower than the mean for the period, and strongly indicating decreases in the annual values of precipitation over time. Statistical assessment (Figure 5) indicates a significance negative relationship between total annual precipitation over time with a coefficient of determination ($R^2 = 0.2781$) at $p < 0.05$, and 27.81% of the precipitation variability explained by the decrease of the linear relationship over time. However, in statistically analysing variability of the number of rain days (days with rain occurrence; Figure 6, \in this case are not minimum defined as well the rain is higher than 0 mm), there is no significant change over time ($p < 0.05$, R2 = 0.0371), and this climate indicator remain stable even although precipitation decreases.

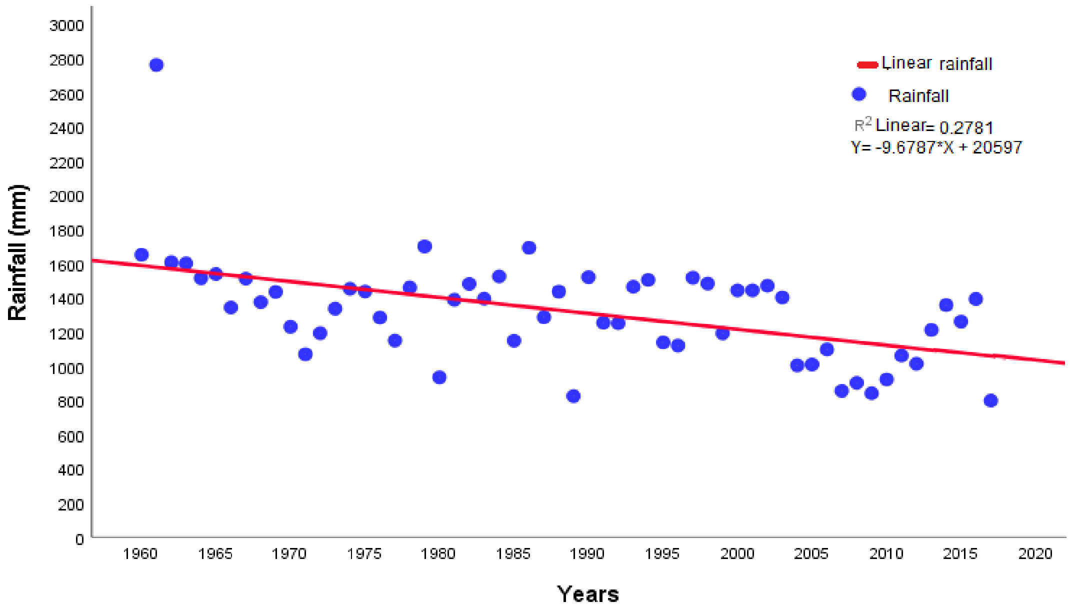

Figure 5: Annual total rain variability over time, Chianga – Huambo 1960-2017 climate data set, Huambo.

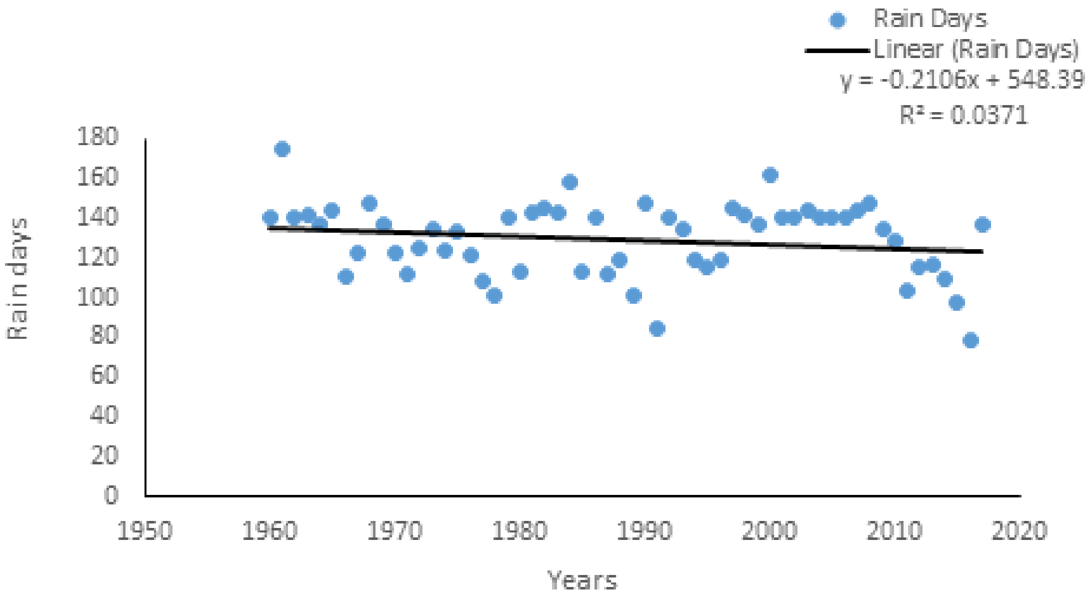

Figure 6: Total annual rain days variability, Chianga – Huambo 1960-2017 climate data set, Huambo.

Change in the rainy and dry seasons. Figures 7 and 8 indicate changes to the rainy season over the data set period, evidencing later commencement, earlier ending and concomitant extension of the dry season. Typically, the rainy season has started during August or September in Huambo region but there has been a progressive increase in the number of months with less than 100 mm of rain by decade. In the first two decades, from 1960 to 1979, the months with precipitation below 100 mm was 3 months from June to August. In 1980-2009 there were 4 dry season months and from 2010 to the present, 5 months from May through to September. These observations give further indication of reduction of rainfall amount and distribution across the months even though the number of rainy days remains stable.

The late onset of rains can cause serious problems in the productive processes of subsistence family farming and in particular due to delays at the beginning of the sowing period, and lack of soil moisture availability making crops exposed to various risks if forced to grow out of their best development period. This may also contribute to a higher probability of pest and disease incidence resulting in further reduction in crop yields [31, 32, 33, 34]. New adaptations in subsistence agriculture practices (land ploughing, sowing time, improved cultivars, small irrigation systems water storage and improved crop seeds) are needed in response to the new reality of intra-annual variability in rainfall and to manage the year-on-year variabilities that make farming decision difficult and long-term sustainable farming hard to achieve.

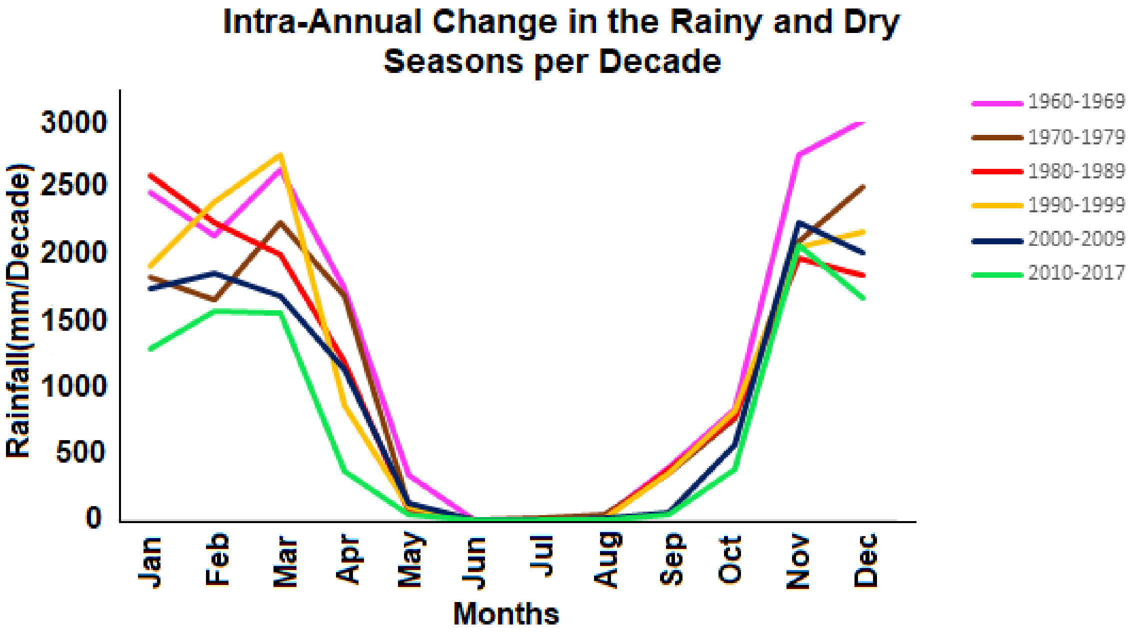

Figure 7: Analyses of dry season and start rain period over time in Huambo.

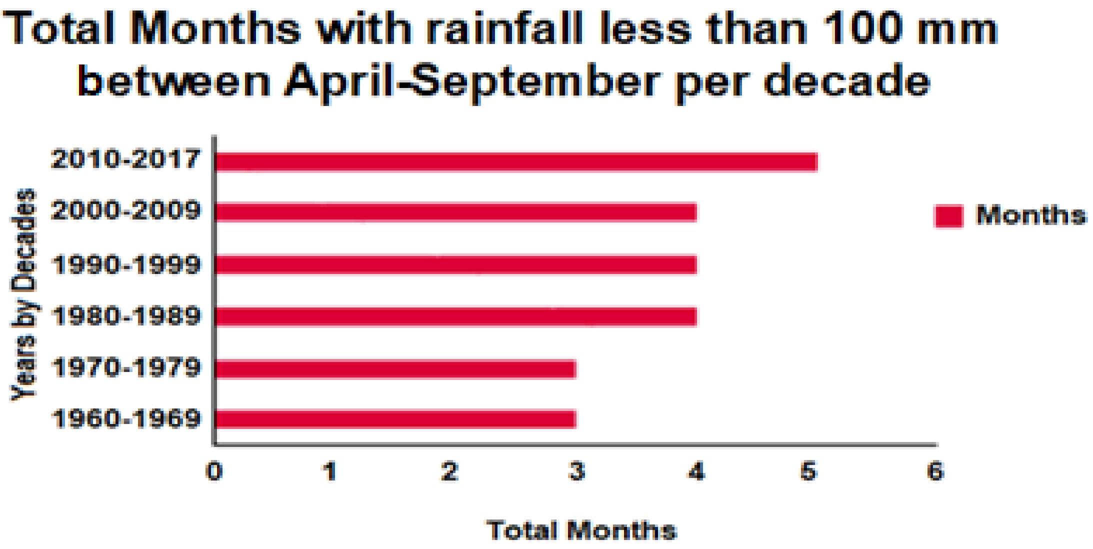

Figure 8: Analyses of variability of dry season and start rain period over time (April-September) per decade, Chianga – Huambo 1960-2017 climate data set, Huambo.

3.4. Year on year rainfall variability

The fluctuation of precipitation that occurred in the period under study shows that there is a big difference between the amount of rainfall that occurred in the years 1961 and 1962, with values of 1154.5 mm and 1110.1 mm, respectively. This difference can be caused by the occurrence of any abnormal change in precipitation due to a natural phenomenon that may have been cyclone or extreme rain invent happened in region in 1961. Likewise, years with values greater than 500 mm can also be observed from year to year, as in the 1980s. 1986, 1989, 1990 and 2017 with 766.2 mm, 542.8 mm, 611.5 mm and 699.6 mm and 594.2, respectively (Figure 9).

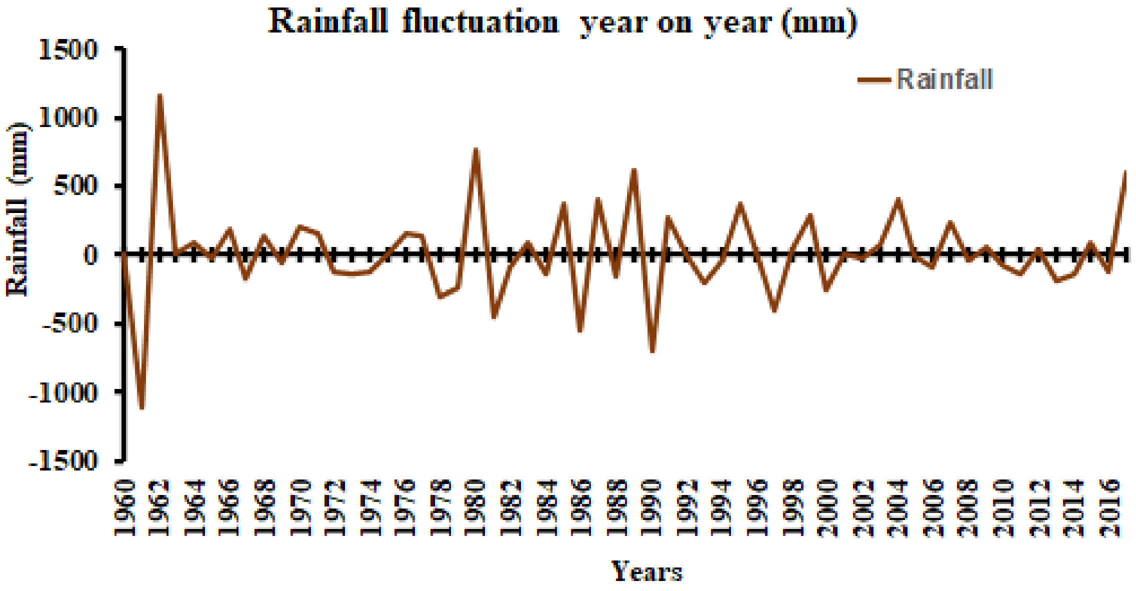

Figure 9: Rainfall variability year on year in Huambo Province, Angola.

In combination observations from the precipitation data suggest that rainfall intensity is in general declining year by year highlighting earlier analyses anticipating climatic conditions in the Southern Africa region will become warmer and drier and that Southern Africa is suffering substantial decreases in precipitation with the El Niño Southern Oscillation (ENSO) phenomenon contributing to a decline rainfall of about -0.6 mm/day with simultaneous drought risks [35].

3.5. Projecting climate futures for Huambo. Temperature and precipitation

Projection of future temperature and precipitation changes over 83 years to 2100 is based on the Chianga – Huanbo 1960-2017 climate data set, Huambo and developed as regression, correlation and autocorrelation analyses between climate parameters (temperature and precipitation) and time. These analyses indicate future trends in inter-annual temperature and precipitation change assuming consistent atmospheric dynamics over the period of analyses (Figures 10 and Figure 11). These analyses indicate that Huambo province will continue to warm year on year, with a projected increase of 0.04^{o}C per year (Figure 10). During the period considered, the amount of rainfall is projected to decrease by about 9.16 mm per year (Figure 11).

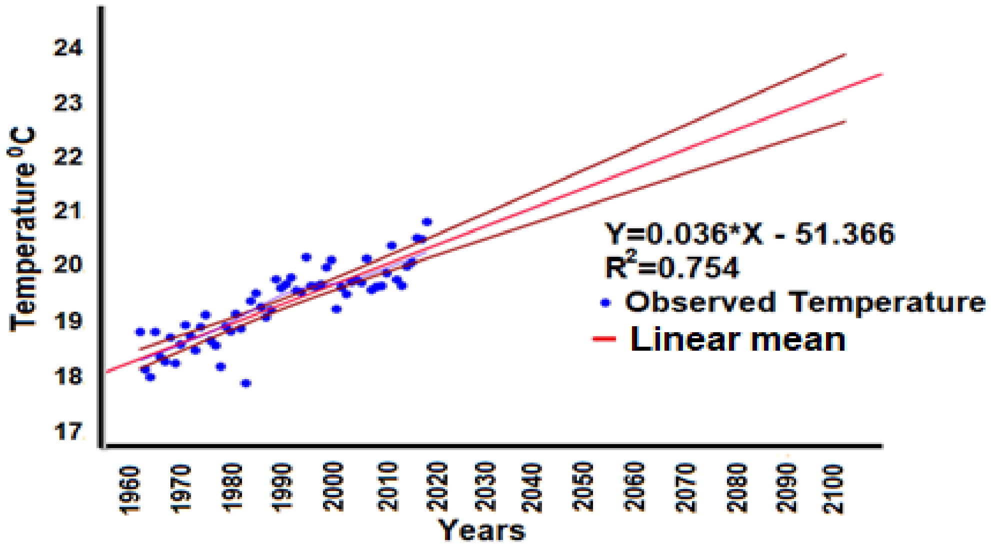

Figure 10: Observed annual average temperature and mean projections for the next 58 year. Based on projection from Chianga – Huambo 1960-2017 climate data set, Huambo.

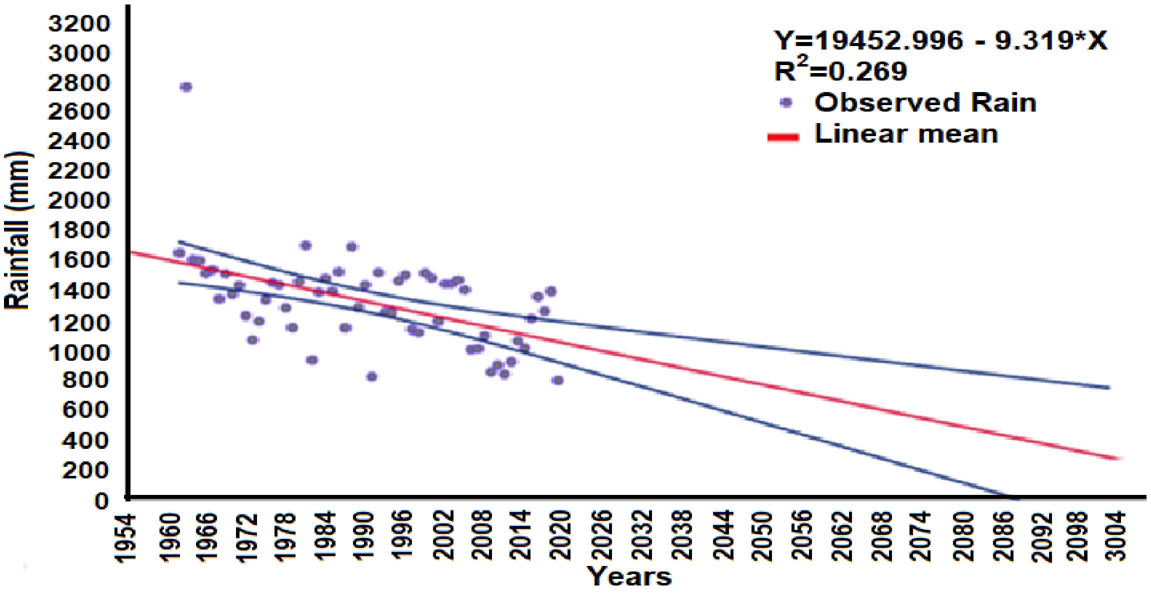

Figure 11: Prediction of average annual rainfall for the next 83 years. Based on projection from Chianga – Huambo 1960-2017 climate data set.

To verify the accuracy of the models, comparison was made between the observed historical data series and the prediction series over time, through the generation of the Autoregression Moved Average model (ARIMA model). The analyses performed created prediction models that fit the existing data at the 95% confidence interval. The series of temperature and precipitation data observed, and the models predicted for data series are presented in Figures 12 and 13 respectively. The results show that the variabilities in the series of forecast data generated by the model do not differ significantly from the data set observed.

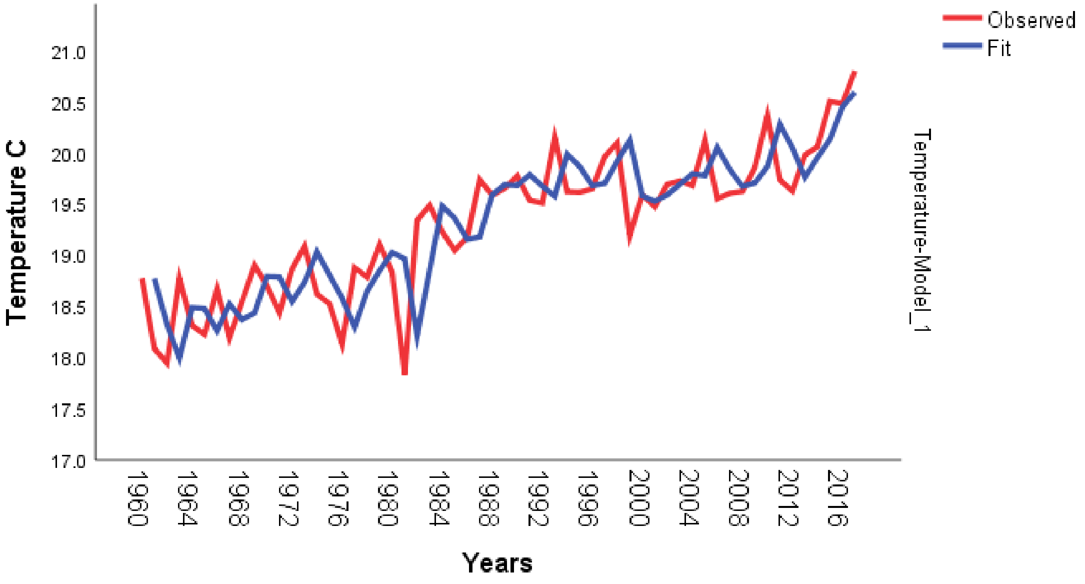

Figure 12: Observed and statistically fitted series of mean temperature (ARIMA model, 1.1.0). Based on Chianga – Huambo 1960-2017 climate data set, Huambo.

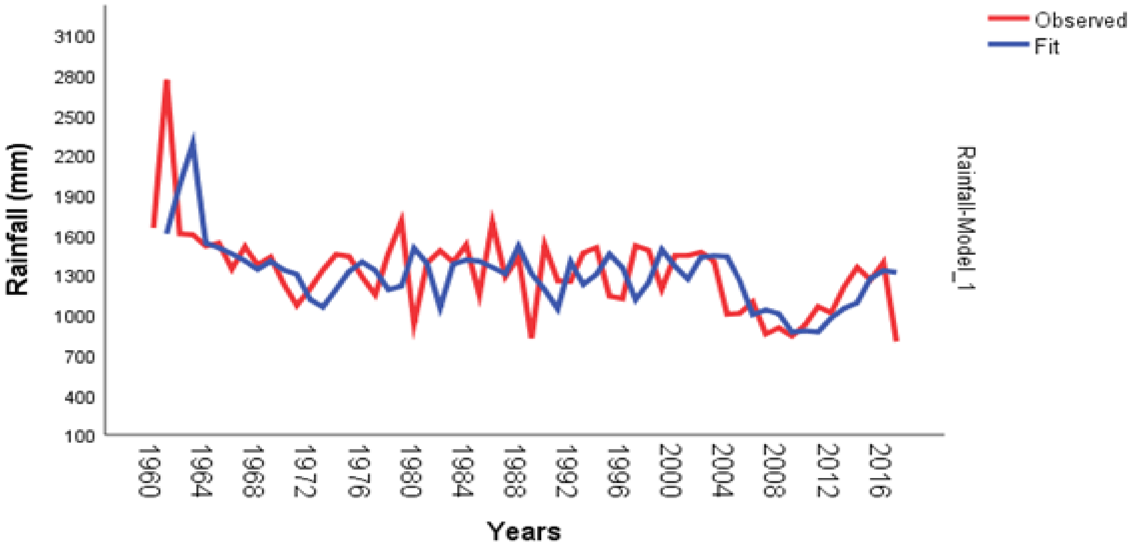

Figure 13: Observed and statistically fitted series of mean precipitation (ARIMA model, 1.1.0). Based on Chianga – Huambo 1960-2017 climate data set, Huambo.

To verify the best fit and suitability of the models it was necessary to examine the residual through the autocorrelation function (ACF) and the partial autocorrelation function (PACF), in which residues are observed within 95% of the confidence interval (Figure 14 and 15). No patterns were observed in the residues reinforcing the veracity of the models to represent the projected data and indicating a strong performance efficiency in the model. In addition to testing whether the estimated parameters are statistically significant, the analyses also ensured that the autocorrelation plot and partial autocorrelation of the obtained model residuals are useful for identifying specification errors as confirmed in Figures 14 and Figures 15.

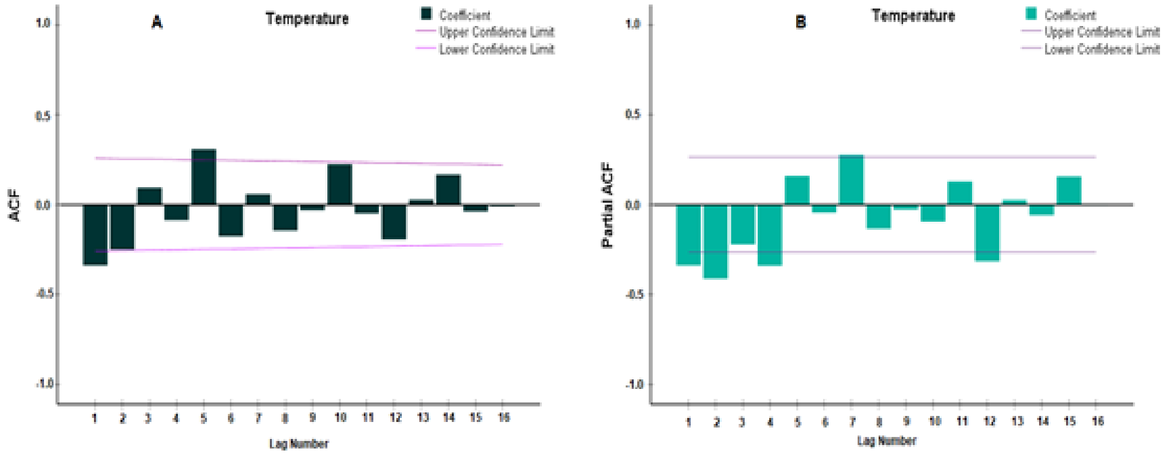

Figure 14: Residual plots of a) autocorrelation function and b) partial autocorrelation function of maximum temperature.

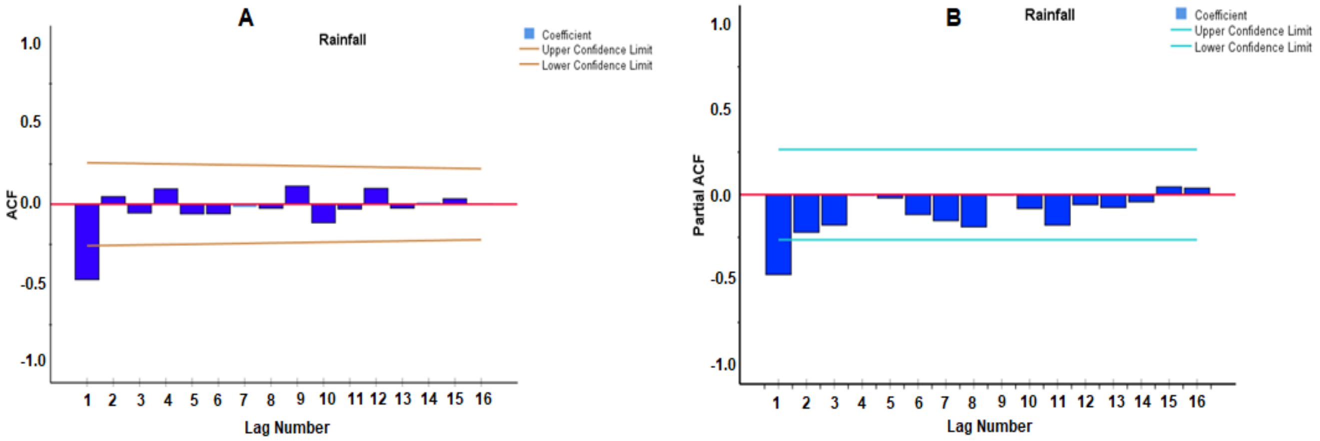

Figure 15: Residual plots of a) autocorrelation function and b) partial autocorrelation function of total rainfall.

4. Conclusions

Analyses of temperatures recorded in historical climatic data sets from the central plateau region of Huambo Province indicate an average annual increase of 0.05^{o}C per year between 1960 and 2017. This has increased annual temperature approximately 3^{o}C during the last 57 years and is clear confirmation that climate warming is already a fact in Huambo. There is an associated reduction in rainfall with year on year decrease in precipitation estimated as 34.45 mm. Critically, dry season months have increased from three to five. These trends are statistically projected to continue during the mid-21st century. The local nature of these data sets as a first assessment of climate change in the agriculturally important Huambo province has an immediacy and resonance with local government, agricultural extension workers and subsistence farming communities alike. It supports the regional trends evident in climate change as well as providing new information on rainfall variability and changes to the rainy season. Work is now ongoing to link these local climate analyses to practical guidelines for subsistence land management that are easily accessible to the farming family.

The analyses have also become a starting point for addressing the impact of climate change on household agriculture in Huambo province. Our interviews with agricultural extension workers and subsistence farmers on the implications of the analyses brings forward concerns for the future [36]. Increases in temperature, leading to accelerating evapotranspiration, together with the decreases in precipitation and crop water availability are recognised as having a direct and negative impact on the productivity of subsistence farming. The secondary outcomes of adding risk to social sustainability of rural communities and aggravating regional food security are also recognised.

Outlines of future adaptations in subsistence agriculture are also emerging. These include spatial planning that recognises the new climate reality, a focus on soils of better water holding capacity, the prospects for water storage and the consideration of new crop varieties [37, 38]. In view of the widening in year on year variabilities in temperature and precipitation and its impact on agricultural productivities there is also recognition of the need to plan support for communities through what may be considered 'lean' years. Our analyses of the Huambo Province climate archives give urgency to these tasks.

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