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Time Series Trend and Variability Analysis of Rainfall in Bale Highlands, Southeastern Ethiopia

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Abstract

Time series analysis is the major tool to detect decreasing or increasing trends and its magnitude in time dimension were tested. Daily historical rainfall data from 1984-201 was considered for this study area. In this study, trend and variability of rainfall indices was analyzed under historical rainfall data in Bale highlands of south eastern Ethiopia. There was a very strong linear relationship between onset of rainfall and length of growing season than other rainfall features. Thus, years with early onset of rain have longer length of growing season and vice versa. This suggests that decision of crops and varieties with different maturity groups and the decision to determine amount of farm input levels highly depend on onset of the rainfall. Dry conditions were more severe during 2nd decade for Kiremt and Belg seasons comparing with others decades. This result implies that the seasonal climate variability more severe in near decade than others. From this point of view, Agricultural practice could be affected severely in these periods either due to deficit or excess of rainfall required for agricultural activities at Sinana and Robe areas.

Keywords: Rainfall; Rainfall trend; Rainfall variability; Onset; Length of growing period

Introduction

Over the last decades various studies have been conducted to examine rainfall trends in Ethiopia [1-2]. Seasonal rainfall amount, intra-seasonal rainfall distribution and dates of onset or cessation of the rains influence crop yields and determine the agricultural calendar [3]. Characterizing the frequency, intensity, and duration of climate extremes were done by calculating climates indices based on daily time series of rainfall. In the study, statistical analyses were done over the last 33 years since 1984 including the climatologically base period of 1984-2016 as defined in the source code of the RClimDex. Plots and tables of trends for the base period 1984-2016 for some selected indices were generated using the RClimDex, developing scripting R open source software. In order to determine start of rains season in each season, the criterion used in this study was the first occasion when rainfall accumulated in three consecutive days is at least 20 mm and no dry spell of more than 10 days in the next 30 day was used as an actual start of rainy season [4].The median start of rainy season was used as a successful planting date for wheat as it is useful for mitigating seedling establishment related rainfall risks. The start of the rainy season for both small rainy seasons locally called Belg and the main rainy season locally called Kiremt could be easily achieved based on soil water balance model. The end of rainy season was defined by calculation of annual soil water balance available capacity was dropped. End rainy season was defined as the first date when the soil water drops to 100 mm [5] available water exists within 10 days after which there is no rainfall for the next 10 days. Evapo-transpiration was obtained using the Hargreaves ETo equation for calculating end of season during the end of the rainy season. The start of rainy season and end of rainy season criteria was used to determine the length of growing season. Moreover, the probabilities of maximum dry spell lengths exceeding 5, 7, 10, 15 and 20 days was calculated to get an overview of dry spell risks analysis during the crop growing period. The early start of rainy season suggests that crop cultivars of the longer maturity type could do better with the late onset date [6]. The dry spell becomes serious in rain-fed agriculture, particularly for the establishment of seedling and crop planting. In general, a dry spell of any length could occur at any stage of crop growth; however, it is potentially detrimental if it coincides with the most sensitive stages such as flowering and grain filling. Estimation of the probability of a given amount of rainfall and dry spell length is extremity important for agriculture planning [7]. In order to characterize the rainfall anomalies was analyzed.

Materials and Methods

General description of the study area

The study were carried out at Sinana Agricultural Research Center and Robe stations Sinana District, which is a part of highlands of Bale Zone, Southeastern Ethiopia located at 6^0 50' N-$7^0$17' N and 40^0 06' E-$40^0$25' E, 430 km southeast of Addis Ababa. Altitude ranges from 1700 to 3100 meters above sea level (m.a.s.l). The 33 years daily rainfall, as well as sunshine hour duration data was obtained from Sinana Agricultural Research Center (SARC) and National Meteorological Agency (NMA) of Ethiopia. The daily observed climate data were checked for quality and missing values, and patched using Markov chain model of INSTAT v.3.37, scanning weatherman data DSSAT and special macros and graphics for automatic checking and data quality control of RClimDex (Figure 1).

Observed climate data

Thirty three years of rainfall data were used to characterize the seasonal and annual rainfall variability and trends using time series data.

Mann-Kendall's test: Mann- Kendall trend test was employed to detect the trend of climate variability. The Mann-Kendall's test statistic was given as:

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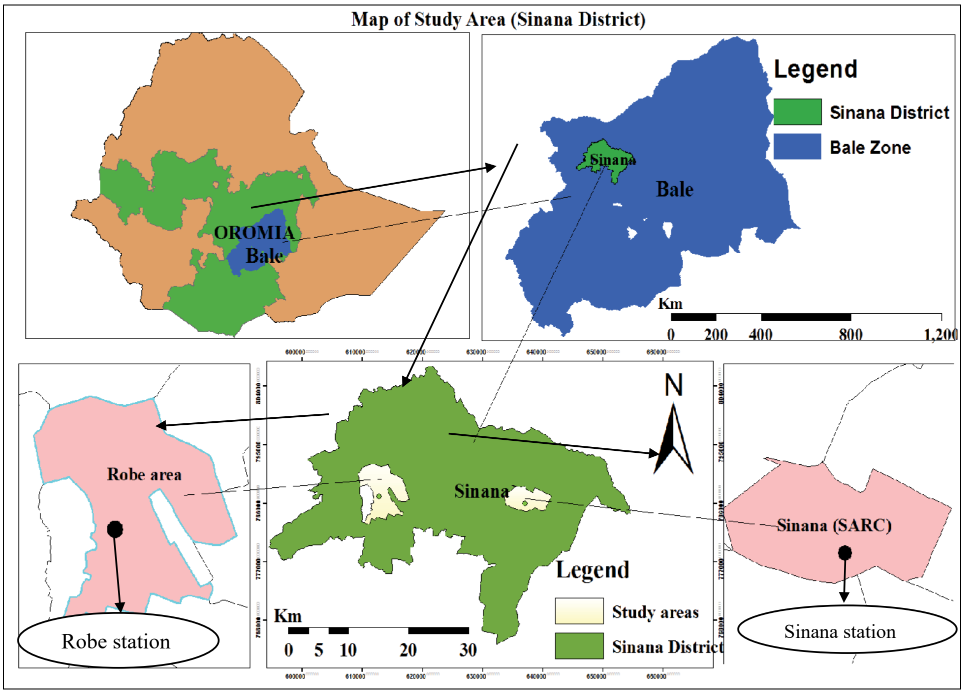

Figure 1: Location Map of the study area (Source: Own sketch).

$$s = \sum_{i=1}^{N-1}\sum_{j=1+i}^{N} \mathrm{sgn}(xj - x_i) \quad (1)$$

Where S is the Mann-Kendal's test statistics; *xi* and *xj* are the sequential data values of the time series in the years *i* and *j* (*j* > *i*) and *N* is the length of the time series. A positive *S* value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The sign function is given as:

$$\mathrm{sgn}(xj - x_i) = \begin{cases} +1 \text{ if}(xj - x_i) > 0 \\ 0 \text{ if}(xj - x_i) = 0 \\ -1 \text{ if}(xj - x_i) < 0 \end{cases} \quad (2)$$

For n larger than 10, Z_{MK} approximates the standard normal distribution was computed as follows:

$$ZMK = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \; if \; S < 0 \end{cases} \quad (3)$$

Where, S is variance and the presence of a statistically significant trend is evaluated using the ZMK value.

The Sen's estimator of slope: This test was applied when the trend supposes to be linear, describing the quantification of changes per unit time. The slope (change per unit time) was estimated above procedure of Sen (1968).

The coefficient of variation of seasonal rainfall variability was analyzed by:

$$CV = \left(\frac{SD}{\bar{x}}\right) * 100 \text{ , Where } \bar{x} = \sum \frac{x_i}{N} \text{ and } SD = \sqrt{\frac{(x-\bar{x})^2}{N-1}} \quad (4)$$

And seasonal rainfall anomaly during kiremt season can be analyzed by:

$$\text{Rainfall Anomaly Index}(RAI) = \frac{X_i - \bar{x}}{SD} \quad (5)$$

Where $\bar{x}$ is long year mean and N is total number of year during observations were held for specific site, SD is standard deviation, X_i is rainfall of each month and RAI is rainfall anomaly of each month. If RAI is more than 0.5, between -0.5 and 0.5, less than -0.5 is meteorologically the month is wet, normal and dry respectively.

Results and Discussion

Time series trend and variability analysis under Sinana and Robe Conditions

The analysis of rainfall revealed changes in extreme values during 1984-2016 in the study area. The analysis of historical rainfall variability and trend was conducted after the quality control was done, missed data was filled. The result indicated that rainfall did not show heterogeneity during 1984-2016 at Sinana and Robe stations. The areas are characterized by a bimodal rainfall pattern with total mean annual rainfall of 905.13 mm and 812.4 mm for Sinana and Robe respectively. As shown in Figure 2 and Figure 3, the area has bimodal rainfall distribution i.e. belg season (short rainy season) in the months of February to May and kiremt (the main rainfall season) extending from June to September.

Additionally, the Mann–Kendall trend test showed a decreasing trend of start of season, end of season and annual number of rainy days at Sinana and end of season and length of growing season at Robe stations; however, it is not statistically significant. This method was based on definition of onset and end date which the INSTAT method based on 20 mm of total rainfall was received over three consecutive days that were not followed by greater than 10 days of dry spell length within 30 days from planting was adopted for both locations. For both areas box and whisker plots for observed start of season, end of season and length of growing season for main rainy season was indicated in Figure 2-3.

Time series trends of rainfall features

Time series of start of season, end of season, and length of growing

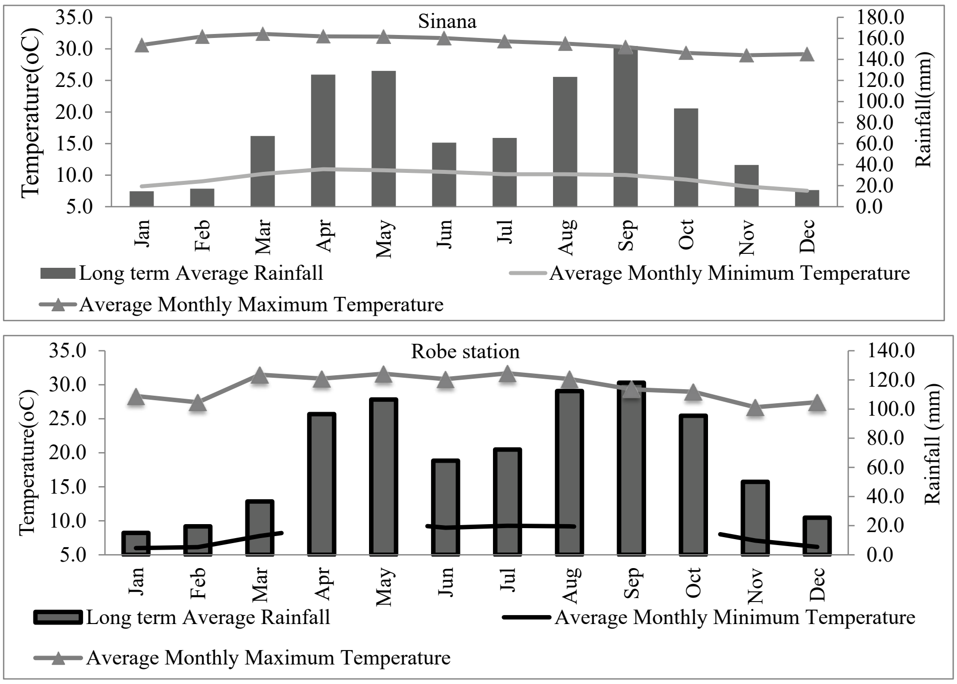

Figure 2: Long term average rainfall and temperature of Sinana and Robe Station (1984-2016).

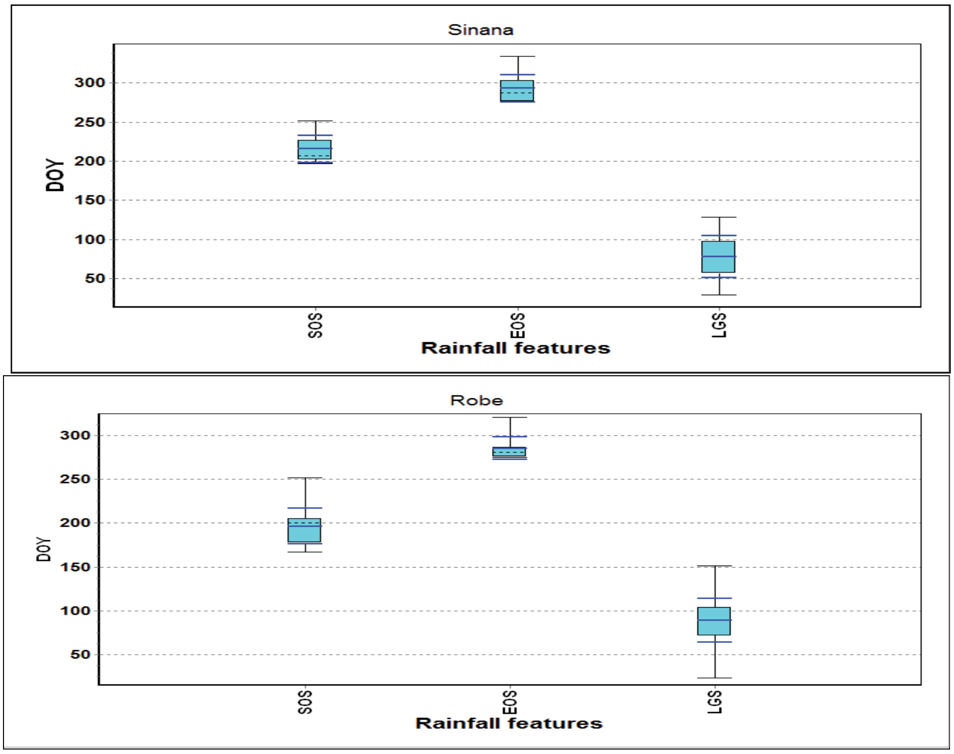

Figure 3: Box and whisker plots for observed start date and end date of growing season (Kiremt season) at two stations in the Bale highland during 1984-2016.

season based on the data of 1984-2016 at Sinana station and Robe stations were presented in Figure 4-7. Total annual and seasonal time series for Sinana and Robe stations revealed increasing trends after the year of 2006 while more increment was shown at Sinana in near decade. There was an observed slightly variability trends of seasons (start, end and length of growing season) at Sinana and Robe stations. Start of season had shown downward slope which indicated decreasing and end of season and growing length of season showed very weak positive trend at Sinana station. In contrast, end of season and growing length of season showed weak negative trend except start of season which revealed slightly positive trend at Robe. The results showed that, no significant trends for end of season while start of season and growing length of season were slightly fluctuated for these study periods. From this point of view, it was possible to confidentially advise the farmers of

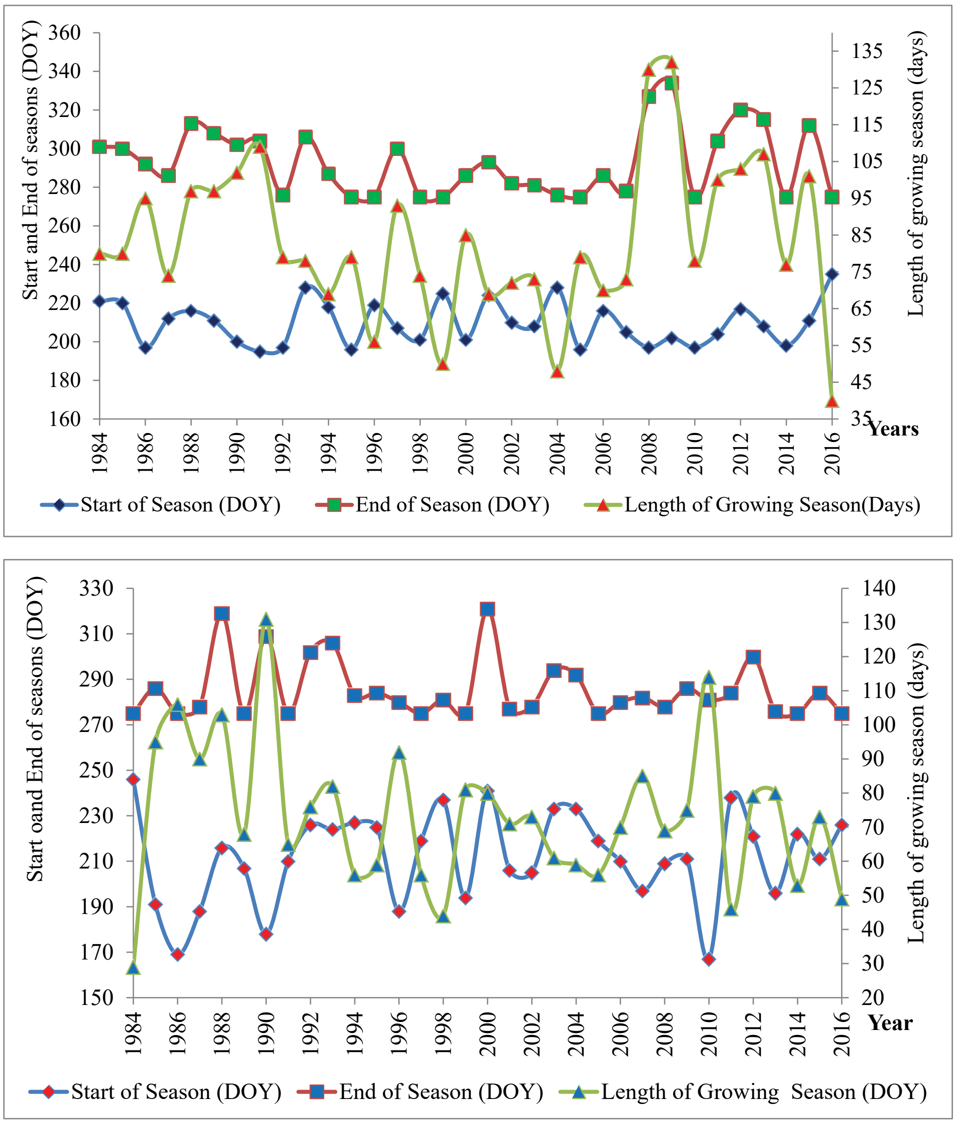

Figure 4: Time series of start of season, end of season, length of growing season based on the data of 1984-2016 at Sinana and Robe station.

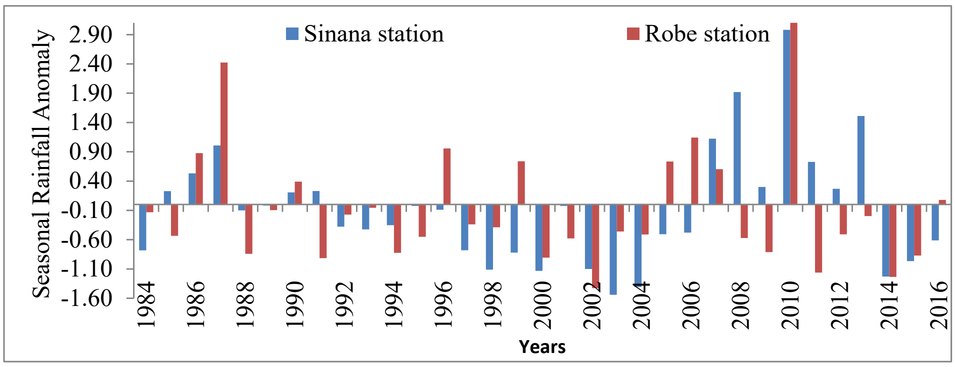

Figure 5: Belg season rainfall anomaly for Sinana and Robe areas for the period 1984-2016.

the area in a way that they could have information like when to plant, the variety to be used and other information pertaining to agriculture precision for their livelihood.

Seasonal rainfall anomalies

Based on historical data of Sinana and Robe stations there was high seasonal rainfall variability over 1984-2016. During the research conducted three decades were considered namely 1st decade (1984-1994), 2nd decade (1995-2005) and near decade (2006-2016) for the study areas. To detect wet and dry conditions of Sinana and Robe areas rainfall anomalies was analyzed. There were wet (0 to +0.5) and dry (0 to -0.5) periods over the study area for seasonal rainfall. During the

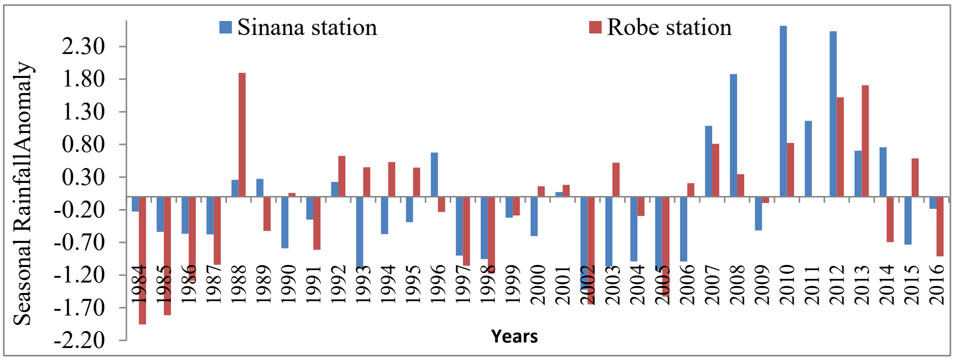

Figure 6: Kiremt season rainfall anomaly for Sinana area for the period 1984-2016.

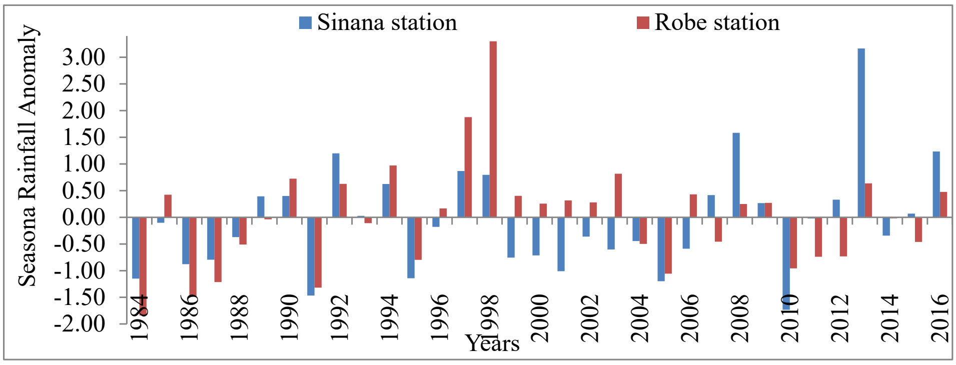

Figure 7: Bega season rainfall anomaly for Sinana and Robe areas for the period 1984-2016.

period of study about six years experienced extreme wet condition, while the most years were received extreme dry condition at Sinana station.

Similarly, extreme wet condition showed in the most years of data received while some years also influenced with extreme dry period at Robe station. Dry conditions were more severe during 2nd decade for Kiremt and Belg seasons comparing with others decades. This result implies that the seasonal climate variability more severe in near decade than others. From this point of view, Agricultural practice could be affected severely in these periods either due to deficit or excess of rainfall required for agricultural activities at Sinana and Robe areas.

Conclusions

The long-term annual rainfall data at Sinana and Robe were analyzed and had shown highly variability for the period of 1984-2016. The areas are characterized by a bimodal rainfall pattern with belg season (short rainy season) in the months of February to May and kiremt (the main rainfall season) extending from June to September. The Kiremt season total rainfall has shown higher variability than the Belg season total rainfall at Sinana. In contrast, for Robe area Kiremt total rainfall was less variable than the Belg season total rainfall. There was a very strong linear relationship between onset of rainfall and length of growing season than other rainfall features. Thus, years with early onset of rain have longer length of growing season and vice versa. This suggests that decision of crops and varieties with different maturity groups and the decision to determine amount of farm input levels highly depend on onset of the rainfall. Dry conditions were more severe during 2nd decade for Kiremt and Belg seasons comparing with others decades. This result implies that the seasonal climate variability more severe in near decade than others. From this point of view, Agricultural practice could be affected severely in these periods either due to deficit or excess of rainfall required for agricultural activities at Sinana and Robe areas.

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