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Analysis of Rainfall and Temperature Variability to Guide Sorghum (*Sorghum Bicolar*) Production in Maitsebri District, Northwestern Tigray, Ethiopia

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Abstract: *Assessing climate variability at specific level has enormous advantages in Ethiopia, in which the driving economy is agriculture. This study was conducted to assess rainfall and temperature variability to guide sorghum production in Maitsebri District. Daily gridded climate data was obtained from the National Meteorological Service Agency of Ethiopia (NMA). Temporal rainfall variability was assessed through the timing of onset date, end date, length of growing season and dry spell length using INSTAT climate guide. Temperature variability was examined in terms of pattern and trend. The long-term annual rainfall showed high variability from year to year with 14.1% coefficient of variation. Seasonally (ONDJF, JJAS and MAM) total rainfall amount showed high variability which was 98.1%, 15.7% and 107% respectively. Rainfall onset date and length of growing season were highly variable. Dry spell length curve converges to minimum from 28June (188DOY) --- 17Sept (261DOY) and diverges on 17October (261DOY) onwards.*

Higher minimum temperature values (>180C) was observed from March to Aril whereas maximum temperature reaches its lowest level in August, but increases again to maximum in April and start to decline as of July. The minimum and maximum temperatures showed an increasing trend both seasonally and annually. To avert the risks of rainfall and temperature variability the use of seasonal climate outlook is recommended for adjusting farm operations and farming system decisions in Maitsebri district and its nearby Areas.

Keywords: *Analysis, Maitsebri, Rainfall, Sorghum, Temperature, Variability, Trend*

1. Introduction

The climate of arid and semi-arid regions of Ethiopia is characterized by high rainfall variability and unpredictability, strong winds, high temperature and high evapotranspiration (Mamo, 2005). It is, therefore, essential to assess rainfall and temperature temporal variability over an area so as to quantify its effects especially on crop yields that could be translated into the best adaptation options according to the development potential and specific challenges under a specific farming zone.

Sorghum [Sorghum bicolor) is the fifth most important staple food crop after wheat, rice, maize and barley (FAO, 2012). It is typically produced under adverse conditions such as low input use and marginal lands. It is well adapted to a wide range of precipitation and temperature levels and is produced from sea level to above 2000 masl (Fetene, 2011). The productivity of sorghum varies across the different parts of the world. Most likely in the Ethiopian-Sudan border regions. The presence of wild and cultivated sorghums in Ethiopia reveals that Ethiopia is the primary center of origin and center of diversity (Mekibeb, 2009). The localized temporal rainfall and temperature variation during cropping season induces an important challenge to sorghum production and in turn to food security. This study was therefore conducted to assess the effects of climate variability on the production of sorghum in Maitsebri district, NW Tigray, Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The study area is located in the Tigray National Regional State of the Federal Democratic Republic of Ethiopia. Geographically, it is located at 13.6^{o}N Latitude and 38.2^{0}E Longitude with elevation between 500 to 1500 m. Agro-Ecological Zone of the study area is Hot to warm-moist lowlands (M1-

7). The mean annual temperature ranges from a minimum of 16°C (November-January) to a maximum of 34°C (February-May). The annual rain fall is 670 mm with a variation between758-1100 mm and has a mono-modal pattern. Generally, rain fall starts in June and ends in September. (CLIMATE-DATA.ORG)

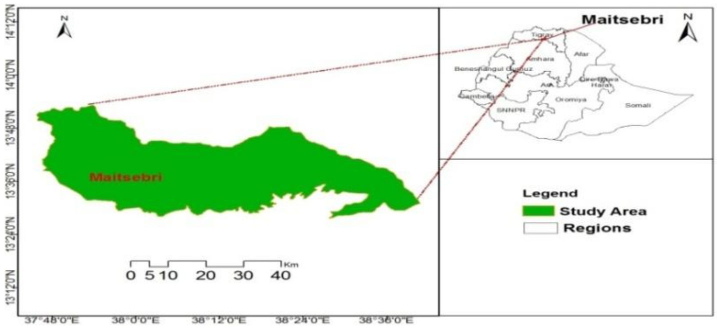

Figure1. *Map of the study area.*

2.2. Climate Parameters and Database Used for the Study

Daily gridded data of rainfall, maximum and minimum temperatures (1985-2015), were collected from the National Meteorological Agency of Ethiopia (NMA).The daily gridded climate data were arranged in day of year (DOY) format for processing. Missing values were patched using Markov chain simulation model of INSTAT v.3.36 (Stern *et al.*, 2006). Quality control check was also done for maximum and minimum daily temperature values by running a macro (Stern *et al.*, 2006) which undertakes automatic checking (minimum temperature greater than maximum temperature) and graph the data for any of the years that fail the check.

2.3. Rainfall and Temperature Variability

Twenty years of gridded rainfall, maximum and minimum data was used to examine temporal seasonal and annual rainfall variability. The long-term rainfall amount and temporal distribution during the growing season of the District was examined by processing the daily rainfall data using INSTAT Climatic Guide (Stern *et al.*, 2006). The temporal rainfall variability such as onset date, end date, length of growing period and probability of dry spell lengths analysis was done for each year. In order to determine onset of rainfall in the JJAS season, the definition of effective onset of rainfall was employed from past rainfall data.

In this study, the first occasion after March 1st when rainfall accumulated in three consecutive days is at least 20 mm and no dry spell of more than 7 days in the next 30 days was used as an actual onset of rainfall. The end of growing season (end date), on the other hand, was defined as the first date after 1st September when the soil water drops to 10 mm/meter within 10 days after which there is no rainfall for the next 10 days. The onset and end date criteria were used to determine the length of growing season as total number of days from the date of onset of rainfall to the end date of the rainfall. Moreover, the daily rainfall data was processed to give probabilities of maximum dry spell lengths exceeding 5, 7, 10, 15 and 20 days starting from January first.

Monthly pattern of average minimum and maximum temperature values were analyzed using the box and whisker plots of INSTAT-Climate Guide (Stern *et al.*, 2006). In a box and whiskers plotting, the box represents the middle 50% of the whole data set, while whiskers represent the magnitude of the spread of the rest of the data set about the median or mean (Stern *et al.*, 2006).

Therefore, in order to quantify its effects on sorghum production trend, seasonal (June-July August-September (JJAS) and annual minimum and maximum temperature anomalies were analyzed.

3. RESULTS AND DISCUSSION

3.1. Annual and Seasonal Rainfall Variability

The amount and distribution of annual and seasonal total rainfall, timing of onset and end dates, and length of growing seasons (LGS) are critical rainfall features that indicate useful information on temporal rainfall variability over an area. The seasonal total rainfall ranged from 572 mm to 993 mm in JJAS. The CV is much higher for MAM season rainfall total than JJAS season rainfall indicating higher temporal variability of the MAM season rainfall total (Table 1). The annual total rainfall also showed high variability and ranged from 648 mm to 1023 mm. The JJAS season rainfall contributes 91.3% of the annual total rainfall.

Table1. *Annual and seasonal (JJAS, MAM and Rest months) total rainfall descriptive statistics for Maitsebri District (1995-2015)*

Descriptive statistics	Annual rainfall total (mm)	Seasonal rainfall total		
		JJAS (mm)	MAM (mm)	Rest months (mm)
Maximum	1023	993	202	83
Minimum	648	572	0	0
Mean	808	737.8	46.2	24
C.V	14.1	15.7	107	98.1
SD	114.1	115.7	49.5	23.5
Proportion (%)	---	91.3%	5.7%	3%

3.2. Onset, End Date and Length of Growing Season

The lower (20th percentile), median (50th percentile) and upper quartiles (80th percentile) of the cumulative probability (Figure 1) Shows the existing variability of the onset date, end date and LGS at Maitsebri District. The lower and upper quartiles of the timing of onset of rainfall are in a range of 162 (June 10) -- 173 (June 21) DOY. Therefore, planting earlier than 10 June is possible in Maitsebri once in five years' time. On the other hand, planting earlier than 21 June (173 DOY) is possible four in every five years' time. In general, the median onset date 169 DOY (17 June) could be taken as a dependable planting date at and around Maitsebri District.

On the other hand, the rainy season terminates in the first dekad of October (278 DOY) once in five years' time and earlier than second dekad of October (288 DOY) in four out of five year (Table 2). Accordingly, the rainy season could not extend beyond the first dekad of October (283 DOY) at Maitsebri district. Therefore, decisions related to harvesting, transporting and storage or marketing could be made more easily than the decision related to planting (Mamo, 2005). The other vital rainfall feature to be considered from crop production point of view is the variation in length of growing season. The probability that the LGS will be shorter than 115 days is 50% while the probability that it will be longer than 124 days (Table 1.) The mean LGP in Maitsebri is 116 days. The LGP variability at Maitsebri District is mainly attributed to high variability in onset of rain as the rainfall end date variability is less.

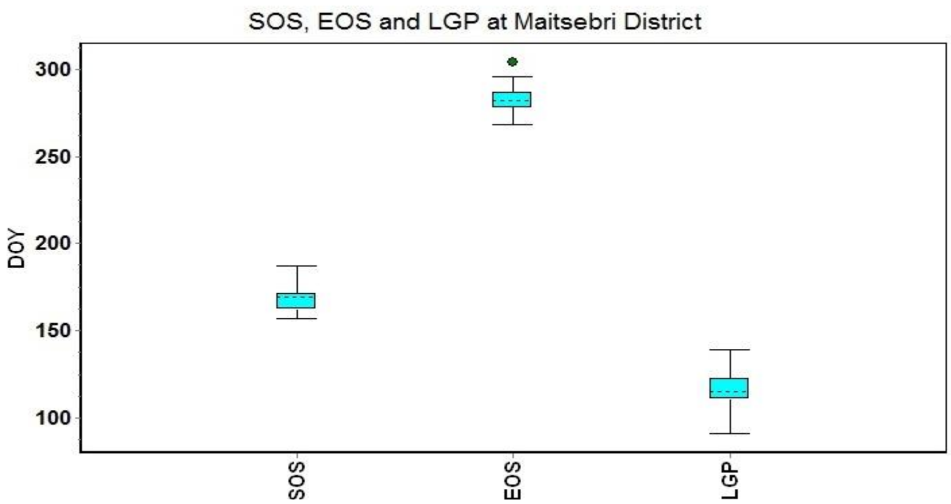

Figure2. *Box whisker plots of onset date, end date and length of growing Period for Kiremt Season at Maitsebri District (1995-2015).*

Table2. *Descriptive statistics of important rainfall features for Maitsebri District.*

Seasonal Rainfall features	Minimum	25%	50%	75%	Maximum	Average	Median
Onset date (DOY)	157	162	169	73	187	168	169
End date (DOY)	268	278	282	88	304	283	282
LGP (DOY)	91	109	115	124	139	116	115

3.3. Probability of Dry Spell Length

Probabilities of dry spell lengths computed during crop growth periods are crucial to determine seedling establishment and potential crop performance at different growth stages. The occurrence of higher probability of dry spell lengths at critical stages of the crop growth are damaging specially at flowering and grain filling stages. The probability of dry spell lengths greater than 5, 7, 10, and 15 days starting from May were computed for the study area (Figure 3). The probability of dry spells longer than 5 days decreases gradually starting from 153 DOY (first dekad of June) until the peak rainy period during July and August. The 5 days dry spell probability starts to rise from about 60% to 100% during September. Similarly, probability of dry spells longer than 7 days start to decrease below 80% from DOY 153 and the curve converges to minimum from 28June/188DOY up to 17Sept/261DOY (Figure 3).

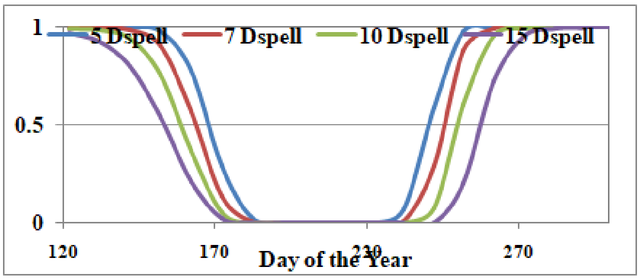

Figure3. *Probability of dry spells longer than 5, 7, 10, 15 and 20 days at MaitsebriDistrict starting from January first.*

Moreover, probability of receiving longer dry spells increase rapidly from second decade of 17 October (261 DOY) indicating the seriousness of terminal drought immediately after the end of rains at Maitsebri District. Likewise, if a farmer cannot decide to take risks of longer dry spells after planting (called risk averse), has to wait until all dry spell probabilities attain minimum values starting 05June (157 DOY).

3.4. Minimum and Maximum Temperature Pattern

Global warming has considered being the major threat for life on our planet. Observations show that global mean temperature at the earth"s surface was increasing over the twentieth century [IPCC, 2013]. Many low-income countries are located in tropical, sub-tropical region, or in semiaridnzones, that are particularly vulnerable to shifting weather patterns and rising temperature (Joachim, 2008). In line with this, the study area was experiencing both warm and cool over the last 30 years; however, the recent once are the warmest as compared to earlier years. The box and whisker plots (Figure 3) illustrate patterns of monthly average minimum temperature at Maitsebri District using long-term historical gridded climate data from 1995-2015. The minimum temperature falls gradually below 10^0C on December representing a relatively cold period during crop harvesting stage of sorghum at Maitsebri (Figure 4). On the other hand, higher minimum temperature values (>14^0C) are observed from April to June (Figure 4). Figure 5 also conveys similar message pertaining to observed maximum temperature of Maitsebri District. The maximum temperature reaches its lowest level in August, but increases again to a maximum in September and start to decline as of July. Therefore, the maximum temperature follows a decreasing trend from June to August and an increasing from September to April.

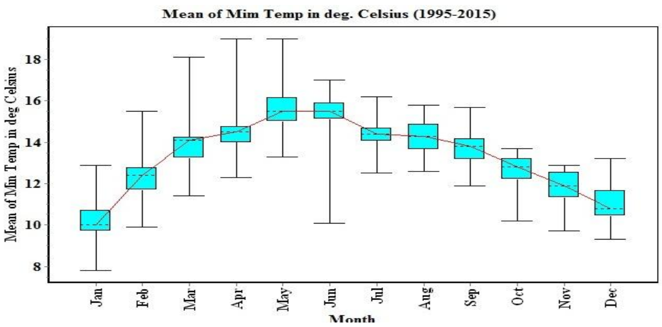

Figure4. *Average minimum temperature box plot by month at Maitsebri District for a period of 20 years (1995-2015).*

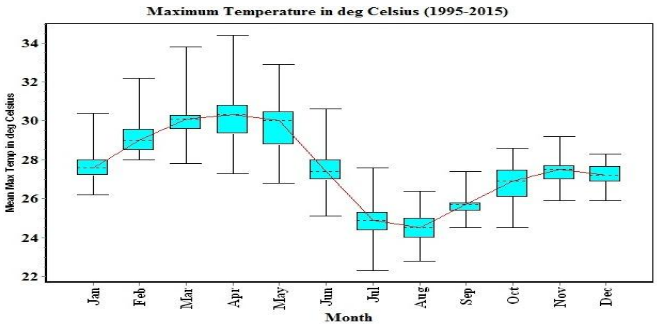

Figure5. *Average maximum temperature boxplot by month at Maitsebri District for a period of 20 years (1995-2015).*

3.5. Annual and Seasonal Maximum and Minimum Temperatures Trend

As seen from Figure 6. And Figure 7. Below, the annual and seasonal maximum and minimum temperatures have been showing significantly increasing. Similar result was reported by (NMA, 2007).

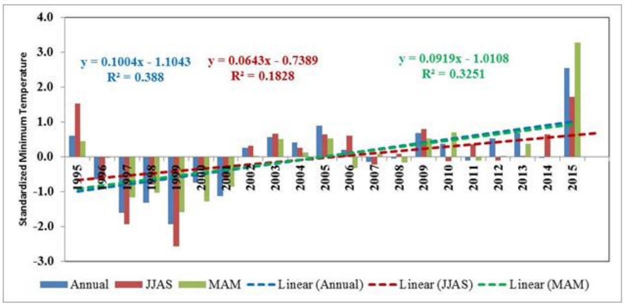

Figure6. *Standardized Annual and Seasonal Maximum Temperature Trends*

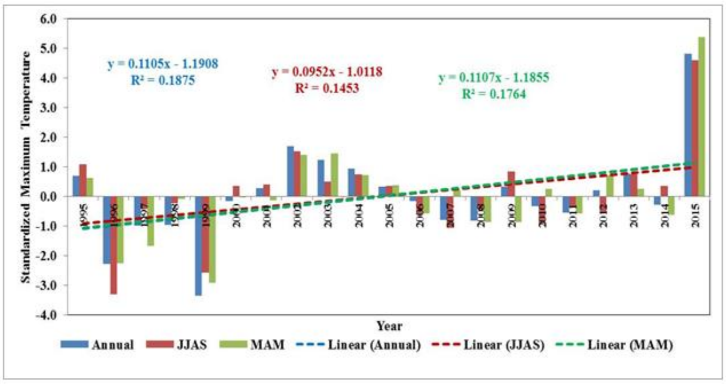

Figure7. *Standardized Annual and Seasonal Minimum Temperature Trends.*

4. CONCLUSION

Except rainfall onset date, all the rainfall parameters analyzed showed high temporal variability. Both average annual and seasonal maximum and minimum temperatures also showed an increasing trend. Therefore, Sorghum producing farmers at Maitsebri District and its surrounding areas should use seasonal climate outlook for adjusting their farm operations and farming system decisions to avert the risk of rainfall and temperature variability.

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