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ANALYSIS OF RAINFALL AND TEMPERATURE VARIABILITY TO GUIDE SORGHUM (SORGHUM BICOLAR) PRODUCTION IN MIESSO AREAS, EASTERN ETHIOPIA

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ABSTRACT

Assessment of climate variability at local level has enormous advantage in Ethiopia, where the driver of the economy is agriculture. This study was conducted to analysis rainfall and temperature variability to guide sorghum production in Miesso. Daily 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, trend and probability of exceedence. The long-term annual rainfall showed high variability from year to year with 25% coefficient of variation. Seasonally, the MAM total rainfall showed high variability than the JJAS total rainfall at Miesso. Rainfall onset date and length of growing season were highly variable. Higher minimum temperature values (>16 °C) are observed from April to August whereas maximum temperature reaches its lowest level in December, but increase again to maximum in June 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 Miesso areas.

Keywords: Analysis, Miesso, Rainfall, Sorghum, Temperature, Variability.

Contribution/ Originality

This study provides recent information on rainfall and temperature variability of Miesso meteorological station. This will help researchers, development planners and farmers to use climate information to adjust their farm level decisions to alleviate the risks of temporal seasonal climate variability in the area.

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1. INTRODUCTION

The issue of climate variability has become more threatening not only to food security and sustainable development of any nation, but also to the totality of human existence. About 66% of the total areas of Ethiopia fall within arid and semi arid climatic zone of the country (MoA (Ministry of Agriculture), 1998). Nevertheless, agriculture, which is highly sensitive to climate variability, is the driver of the country's economy as it accounts for half of Gross Demostic Product (GDP) and 80% of employment (MoARD (Ministry of Agriculture and Rural Development), 2007). Thus, the dependence of Ethiopia on agriculture makes its economy extremely vulnerable to the risks associated with climate variability. Moreover, the projected higher temperature and variable precipitation levels will unequivocally depress crop yields through direct effects as well as indirect impact by triggering insect pests, diseases and weeds (Gadgil *et al.*, 1998). Therefore, climate variability is and will form a serious concern for both researchers and development planners in Ethiopia.

The seasonal climate variability of Ethiopia, particularly rainfall, is influenced by weather systems of various scales; from mesoscales, to the large scale, mainly El Nino-Southern Oscillation (ENSO) related phenomena (NMSA (National Meteorology Service Agency), 1996). The climate of arid and semi arid region 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 one of the crops mostly grown in wide agro ecological zones throughout the world. The crop appeared to have been domesticated in Ethiopia about 5000 years ago (Taylor, 2003). Currently, large part of sorghum production areas in Ethiopia fall under the arid and semi-arid regions of the country that are characterized by high rainfall variability and low soil water storage capacity. The crop is widely grown in low moisture areas due to its high capacity to tolerate soil water deficit and wide range of ecological diversity (Kidane *et al.*, 2006; MoARD (Ministry of Agriculture and Rural Development), 2007). Despite its significant area coverage, however, the national average sorghum productivity is 1.302 t ha^{-1}(CSA (Central Statistical Authority), 2005) which is by far less than the developed countries average yield, 3.056 t ha^{-1} (FAO (Food and Agricultural Organization), 2005). The low productivity of sorghum in Ethiopia is attributed to climate, soil fertility and socio-economic factors affecting directly and indirectly its production. The Miesso-Assebot plain, which is located in the eastern escarpment of the Central Rift Valley of Ethiopia, is one of the areas where sorghum is widely grown. 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 Miesso areas.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study area is located in the Eastern escarpment of the Central Rift Valley of Ethiopia that forms the heart and corridor of the Ethiopian Rift Valley. The geographical location of the area ranges between 8° 48" 12'- 9° 19" 52'N latitude, 40° 9" 30' and 40° 56" 44' E longitudes and an altitude 1107 to 3106 meter above sea level. The soil type in the study area is almost entirely volcanic in origin and includes both alkaline (basalts) and acidic rock types (Smith, 1982). The soil texture is mainly Silty Clay Loam with slightly alkaline pH ranging from 7.8 to 8.3 (Worku, 2006; Lemma, 2008). The study area is predominantly categorized under hot and warm sub-moist plain agro-ecological zone (MoA (Ministry of Agriculture), 1998) with level to undulating topography.

2.1. Climate Parameters and Database Used for the Study

Daily rainfall data (1974-2009), maximum (1990-2009) and minimum (1990-2009) temperatures were collected from the National Meteorological Agency of Ethiopia archives (NMA). The daily observed 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.

2.2. Rainfall and Temperature Variability Analysis

Thirty six years of rainfall data from Meisso Meteorological Station were used to examine temporal seasonal and annual rainfall variability. The long-term rainfall amount and temporal distribution during the growing season of the station 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 analyses were done for each year. In order to determine onset of rainfall in each 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 March-April-May (MAM) and (June-July August-September (JJAS) and annual minimum and maximum temperature anomalies were analyzed. Moreover, probabilities of monthly maximum temperatures exceeding 32, 34, 36 and 38 °C were examined from March-July as maximum temperature reaches its climax and potential planting date extends during these months of the year over the area.

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 0 to 527.3 mm in MAM and 231 to 648 mm in JJAS, respectively (Table 1). 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 interannual variability and ranged from 383.2 to 1111 mm. The JJAS season rainfall contributes 56.5% of the annual rainfall whereas the MAM season contributes 27.8% of the annual rainfall. The rest of the annual rainfall (15.7%) is obtained during the dry months of the year (October to February).

Table 1. Descriptive statistics of annual and seasonal (MAM and JJAS) rainfall total of Miesso for 36 years (1974-2009)

Descriptive statistics	Annual rainfall total (mm)	Seasonal rainfall total		
		JJAS (mm)	MAM (mm)	Rest months
Maximum	1111.0	648.1	527.3	438.0
Minimum	383.2	231.8	0.0	0.0
Mean	726.5	410.2	202.0	85.9
C.V	24.7	24.3	60.3	89.0
SD	179.1	99.8	121.8	146.0
Proportion (%)	-	56.5	27.8	15.7

The study area is characterized by a bimodal rainfall type which can be seen separately in terms of crop production. The first is the short rainy season, which extends between March to May and locally known as '*Belg*'. The second is the long rainy season, which extends from June to September (JJAS) and locally known as '*Kiremt*'. The rainfall distribution during this period varies between 44.4 to 144.5 mm with a peak rainfall in August. The bimodal rainfall nature of the area is also indicated by dry spell probability lengths analysis shown in Figure 2.

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 1a, b & c) show the existing variability of the onset date, end date and LGS at Miesso. The moving curve (Figure 1a) shows the high variability of onset date of rainfall as compared to the rest rainfall features. The lower and upper quartiles of the timing of onset of rainfall are in a range of 78 (March 18)-192 (July 10) DOY. Therefore, planting earlier than 18 March is possible in Miesso once in five years time. On the other hand, planting earlier than 10 July (192 DOY) is possible four in every five years time. In general, the median onset date 155 DOY (03 June) could be taken as a dependable planting date at and around Miesso.

On the other hand, the rainy season terminates in the first dekad of September (246 DOY) once in five years' time and earlier than second dekad of September (264 DOY) in four out of five year (Figure 1b). Accordingly, the rainy season could not extend beyond the end of the second dekad of September (258 DOY) at Miesso. The relatively steep curve of the cumulative probability graph for end date of the season (Figure 1b) indicates the predictable nature of cessation of the rainfall in the area. 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 118 days is 50% while the probability that it will be longer than 175 days is 20% (Figure 1c). The mean LGS in Meisso is 115 days. The LGS variability at Miesso is mainly attributed to high variability in onset of rain as the rainfall end date variability is less.

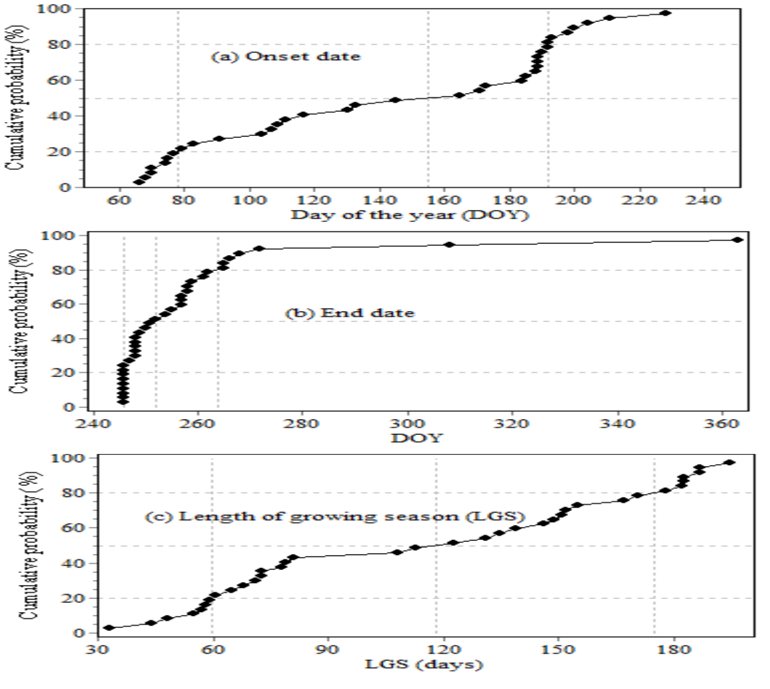

Figure-1. Cumulative probability of onset (a), end date of rainfall (b) and length of growing season (c) at Miesso.

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 dry spell lengths at critical stages of crop growth are damaging specially at flowering and grain filling stages. The probability of dry spell lengths greater than 5, 7, 10, 15 and 20 days starting from January were computed for the study area (Figure 2). 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 during July and August (Figure 2).

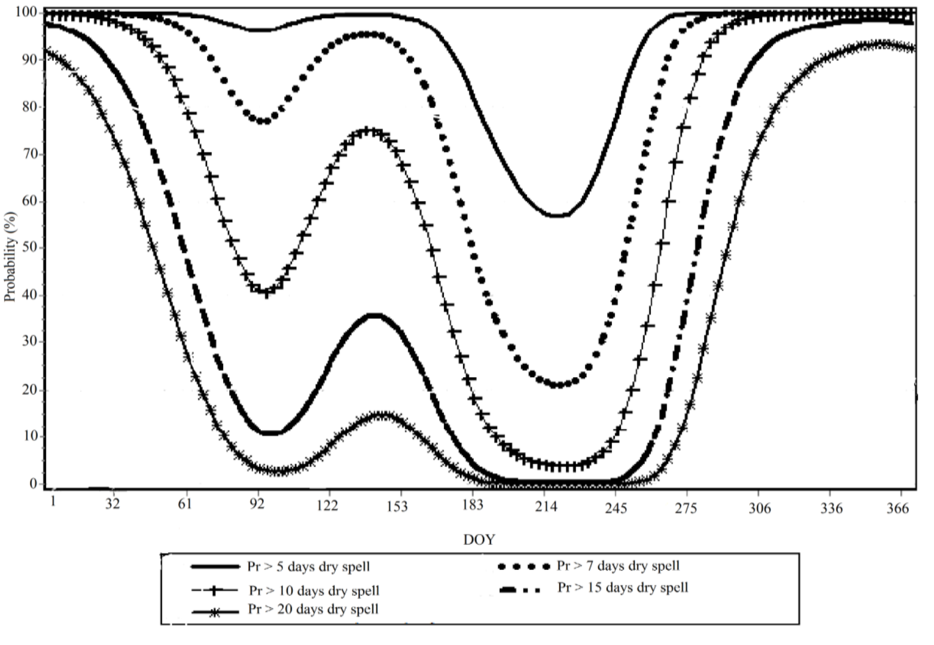

Figure 2. Probability of dry spells longer than 5, 7, 10, 15 and 20 days at Miesso starting from January first.

On the other hand, probability of dry spell length exceeding 10 days is less than 50% starting from second dekad of June until September (first dekad) of the main rainy season. The probability of receiving longer dry spells (longer than 15 and 20 days) is below 20% starting from March (61 DOY) until May (122 DOY). But, the probability of these long dry spells rises gradually to a peak 30% (15 days) and 10% (20 days dry spell) between 122-153 DOY which gradually decrease to zero on 183 DOY (first day of July). Moreover, probability of receiving longer dry spells increase rapidly from first decade of September (245 DOY) indicating the seriousness of terminal drought immediately after the end of rains at Miesso. According to Mamo (2005), farmers who have access to irrigation could take risks of longer dry spells and decide to plant during earliest months of the season. In this case, planting earlier than June 03 is possible for the main rainy season at Miesso. 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 (183 DOY).

As indicated by Tesfaye and Walker (2004), these types of dry spell analysis are important for on farm level agricultural decisions like choice of crop or variety (short, medium or long maturing, drought tolerant or susceptible) and crop management practices (supplemental irrigation, fertilizer and insecticide application). For instance, drought tolerant varieties during early and terminal stages are required if one has to choose to grow long maturing varieties in the study area. However, crop varieties that mature within 80-100 days are needed in order to effectively utilize the rainfall in the JJAS season in Miesso and surrounding areas. Moreover, these types of analyses could provide an overview of each days of the year with varying probabilities of dry spells that could help farmers to adjust farm management practices in a given cropping year.

3.4. Minimum and Maximum Temperature Trend

The box and whisker plots (Figure 3 a & b) illustrate patterns of monthly average minimum and maximum temperature of Meisso weather station using long-term historical data from 1990-2009. The minimum temperature falls gradually below 14 °C during October to January representing a relatively cold period during crop maturity and/or harvesting stage of sorghum at Miesso (Figure 3a). On the other hand, higher minimum temperature values (>16 °C) are observed from April to August (Figure 3a). Figure 3b also conveys similar message pertaining to observed maximum temperature of Meisso. The maximum temperature reaches its lowest level in December, but increases again to a maximum in June and start to decline as of July. Therefore, the maximum temperature follows a decreasing trend from July to December and an increasing from January to June.

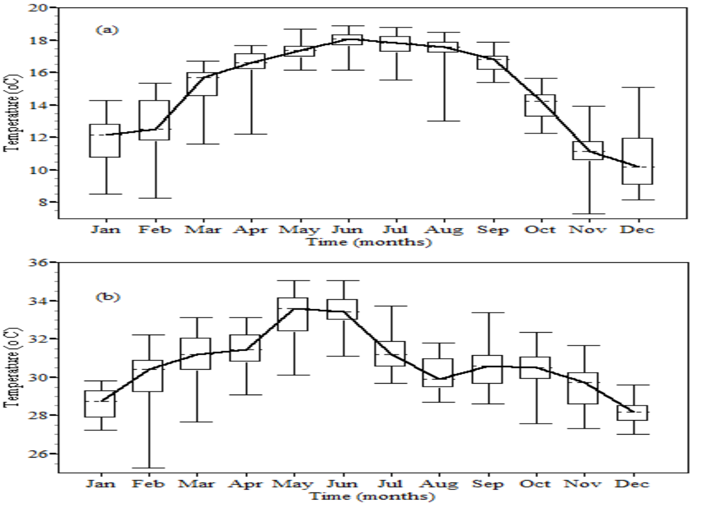

Figure-3. Average minimum (a) and average maximum(b) temperature pattern by month at Miesso for a period of 20 years (1990-2009).

A time series analysis was also conducted for annual and seasonal (MAM and JJAS) average minimum temperatures (Figure 4). The average annual minimum temperature data of Miesso station for the period 1990-2009 shows a relatively increasing trend. The seasonal temperature data also indicates a consistent increasing trend of JJAS minimum temperature while there is a slight increasing trend of MAM average monthly minimum temperature (Figure 4). The JJAS and annual mean minimum temperature are showing a positive increasing trend above the average value starting from 2000.

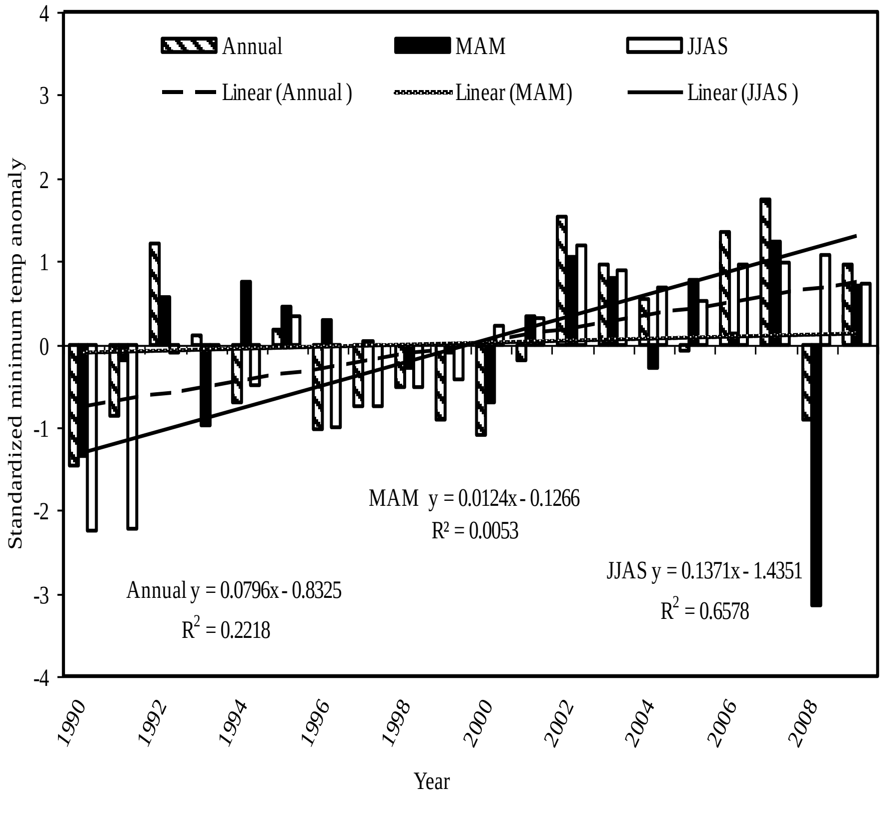

Figure-4. Annual and seasonal average minimum temperature trend at Miesso meteorological station for a period of 20 years (1990-2009).

Such increasing trend of temperature contributes to the increase in the rate of photosynthesis as a result to increased optimum temperature requirement for CO_2 assimilation. This enhances crop growth and development and on the other hand shortens the crop growing season provided that other essential resources are not limiting. However, an increase in temperature is associated with elevated CO_2 concentration. Hence, under high atmospheric CO_2 and increased temperature the efficiency of photosynthesis in C4 crops such as sorghum is reduced which in turn induce low biomass and grain yields (Cousins *et al.*, 2003). Moreover, increase in base minimum temperature values at Miesso justifies increased water requirement of crop due to high evapotranspiration.

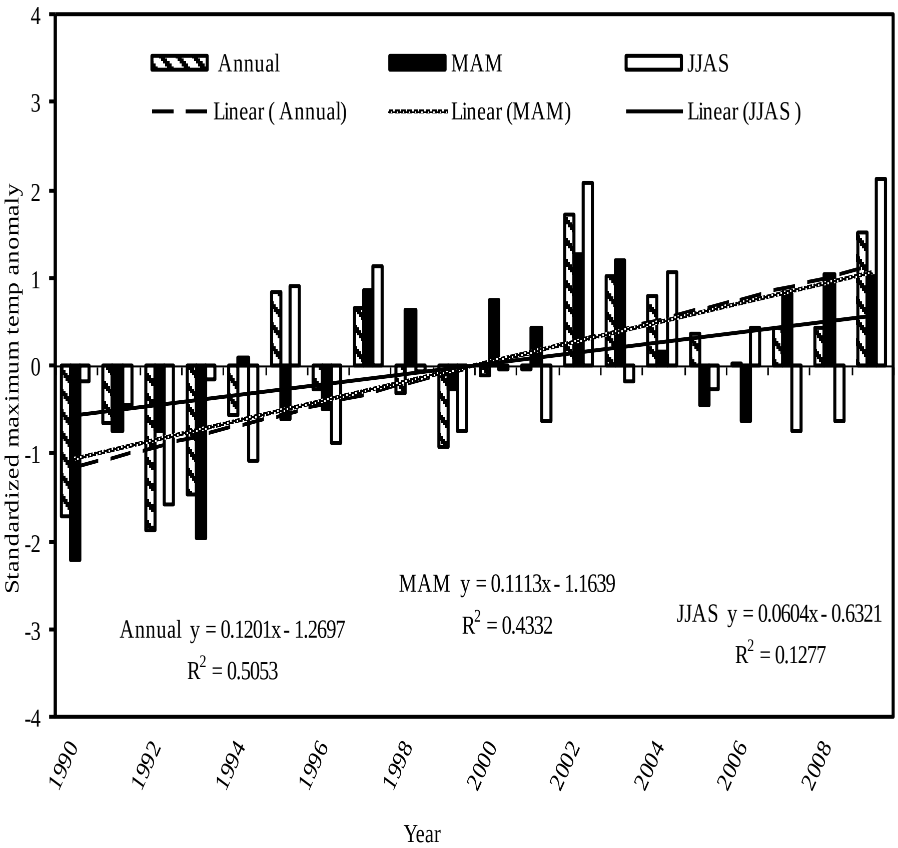

Figure-5. Annual and seasonal average maximum temperature trend at Miesso meteorological station for a period of 20 years (1990-2009).

The standardized maximum temperature anomaly also shows the general trend of maximum temperature at Miesso over a period of 20 years (Figure 5). The annual and MAM average maximum temperature show a consistent increasing trend. But, JJAS average maximum temperature shows a slight increasing trend at the area over the last twenty years. It also reveals that the recent years are getting warmer as compared to the earlier years. These high temperatures (30-40 °C) are expected to reduce biomass and yield of crops as result of reduced growing duration for radiation capture. Wylie (2008) reported that increase in temperature translates into a shift from using long duration cultivars to the short maturing ones, which have lower yield potential.

3.5. Probability of Extreme Temperature Events

Analysis of extreme temperature events exceeding optimum temperature requirement of crops that occurs during crop growth period is crucial as this is a decisive factor to crop yield stability. Probabilities of monthly (March-July) temperature values exceeding 32, 34, 36 and 38

°C were done (Figure 6) assuming that potential planting date extends during these months of the year at the area.

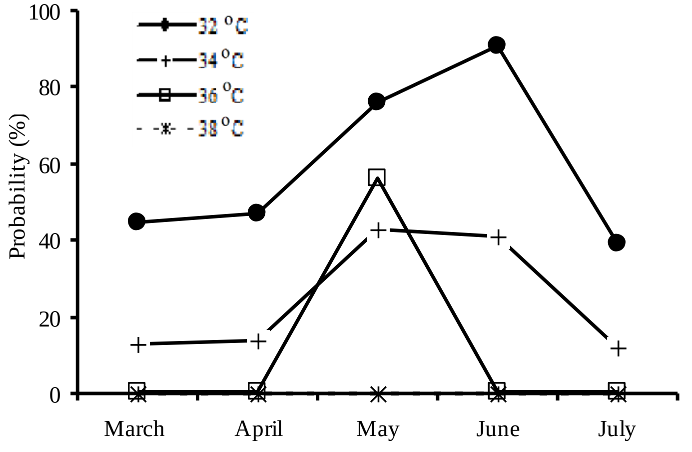

Figure-6. Probability of temperature frequencies exceeding 32, 34, 36 and 38 °C at Miesso.

The probability of maximum temperature exceeding 32 °C showed a consistent increasing trend from March to May reaching maximum (80%) in June, which again declines to 40% in July. In crop production this shows that crops have to withstand a temperature value exceeding 32 °C in eight out of ten days occurring in June. The probability of receiving maximum temperature exceeding 34 °C also shows an increasing trend from March to May and a declining trend in June and July. The probability of maximum temperature exceeding 36 °C is also just about 50% in May while there are no chances of experiencing such value in other months (Figure 6). However, there are no chances of receiving maximum temperature exceeding 38 °C in March-July.

4. CONCLUSION

Among all the rainfall variability parameters analyzed all parameters except rainfall end date showed high temporal variability. Both average maximum and minimum temperature also showed an increasing trend seasonally and annually. Therefore, sorghum producing farmers at Miesso should use seasonal climate outlook for adjusting their farm operations and farming system decisions to avert the risk of rainfall and temperature variability.

REFERENCES

Cousins, A.B., N.R. Adam, G.W. Wall, B.A. Kimball, P.J. Pinter, M.J. Ottman, S.W. Leavitt and A.N. Webber, 2003. Development of C4 photosynthesis in Sorghum leaves grown under free-air CO2 enrichment. Journal of Experimental Botany, 54(389): 1969-1975.

CSA (Central Statistical Authority), 2005. Agricultural sample survey. Report on landutilization, Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

FAO (Food and Agricultural Organization), 2005. FAO statistical data base for agriculture. Rome, Italy.

Gadgil, S., P.R. Seshagiri and S. Sridhar, 1998. Modeling impacts of climate variability on rainfed groundnut. Bangalore, India: Indian Institute of Science. pp: 11.

Kidane, G., T. Abebe and T. Degefie, 2006. Estimating crop water use and simulating yield reduction for maize and sorghum in Adama and Miesso districts using the cropwat model. Addis Ababa, Ethiopia: Ethiopian Agricultural Research Institute. pp: 1-14.

Lemma, W., 2008. Physicochemical studies of soils of Miesso areas, Eastern Hararhge, Oromiya region. MSc Thesis Presented to the School of Graduate Studies of Haramaya University.

Mamo, G., 2005. Using seasonal climate outlook to advice on sorghum production in the central Rift valley of Ethiopia. PhD Thesis, Blomefontein, Republic of South Africa.

MoA (Ministry of Agriculture), 1998. Agro ecological zones of Ethiopia. Ministry of agriculture. Addis Ababa, Ethiopia.

MoARD (Ministry of Agriculture and Rural Development), 2007. Ministry of agriculture and rural development crop development crop variety register. Addis Ababa, Ethiopia, 7: 104.

NMSA (National Meteorology Service Agency), 1996. Climatic and agro climatic resources of Ethiopia. National Meteorology Service Agency of Ethiopia, Addis Ababa, 1(1).

Smith, A.R., 1982. The environment of the Ethiopian Rift valley compared to other areas of Africa. Summary of the ILCA Internal Document, Forage Legume Agronomy Group, ILCA, Addis Ababa, Ethiopia.

Stern, R., D. Rijks, I. Dale and J. Knock, 2006. Instat climate guide. UK: Statistical Service Center, University of Reading.

Taylor, J.R.N., 2003. Overview: Importance of sorghum in Africa. Available from www.afripro.org.uk/papers/paper.

Tesfaye, K. and S. Walker, 2004. Matching of crop and environment for optimal water use: The case of Ethiopia. Physics and Chemistry of the Earth, 29: 1061-1067.

Worku, A.W., 2006. Quantifying rainfall-runoff relationship on selected benchmark ecotopes in Ethiopia: A primary step in water harvesting research. PhD Dissertation University of Free State, Bloemfontein.

Wylie, P., 2008. Managing sorghum for high yields: A blueprint for doubling sorghum production. Dalby.