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Characterizing Climate for Agricultural Production and Best Sowing Dates to Minimize Crop Failure: The Case of Kelte-Awelalo Woreda, Tigray, Northern Ethiopia

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Abstract

The rainfall of the study area is bimodal and had a total of 565 mm/year. However, there had been large rainfall variability between the seasons from year to year. In "Bega" (October-January) coefficient of variation (CV) ranged from 191%-249%, "Belge" (February-May) 85%-185%, followed with "Kiremt" (June-September) 50%-108%. Though, the rainfall season had less CV in compare with other seasons, it creates variability & reduction in agricultural yield. In addition, there had been also a large probability of dry spell occurrences during July (75%) & August (95%) of the main rainfall season. The average onset of rainfall was May 19 followed by an average Cessation August 28 with an average length of growing period 100 rainfall days. The long-term average maximum and minimum temperature was 28^{0}C and 11^{0}C with a cumulative growth degree days of 623^{O}c during grain-filling stage. This leads the crop species to had daily temperature extremes and apparent heat stress. The elevated temperature has also results in high evapotranspiration loss of 123-170 mm/month. Therefore, the optimal planting date for finger millet would be as of mid-May but for wheat, barley and "Hanfets" (mixture of wheat and barley) may be on mid-June to the first week of July.

Keywords: *Evapotranspiration, Length of growing period, Rainfall onset &cessation, Temperature*

1. Introduction

One of the significant impacts of climate change is on agricultural system resulting in declining of crop yields and food insecurity. This would be particularly true in arid and semiarid areas of Africa where water resources are very sensitive to rainfall variability. Scientific evidence indicates that increased concentration of greenhouse gases in the atmosphere causes changing climate of the Earth, increasing of temperature and the amount & distribution of rainfall is being altered (Houghton, 2001).

Developing countries are vulnerable to climate change due to increasing of human population, weak national and regional economies, water scarcity, and poor utilization of natural resources (World Bank, 2010). Moreover, the majority agricultural system by small scale farmers are highly dependent on rainfed agriculture which suffering by unpredictable rainfall and temperature variability, drought and climate risk those results in crop failure and reduction in agricultural yield.

Ethiopia is highly vulnerable to climate change due to dependence on climate sensitive sectors such as agriculture. Agriculture plays a dominant role in the economy of Ethiopia, contributing 41% GDP, 80% of the employment and the majority of foreign exchange earnings (Gebreegziabher Z., Stage J et al. 2011). The success of agricultural production depends on climatic conditions. Therefore, understanding of historical climatic change is important in order to provide framework for agricultural planning, climate risk forecasting and climate change projections, as well as a convincing basis for climate change adaptations.

In Ethiopia, rainfall and temperature is the most important factor that determine crop growth, crop variety choice and grain yield (Sinebo, Lakew et al. 2010). The current climate change is characterized by shorter rainfall season, erratic distribution (in time and space) with decreasing amount from year to year. Rainfall is highly variable in Tigray region, Northern Ethiopia. High variability and unpredictable rainfall pattern have a large bearing on crops sowing date, with important implications for seed acquisition (mainly due to crop failure).

Temperature is also one of the most determinants of crop growth over a range of environments (Summerfield, et al. 1990). Thus increase or decrease in temperature may have significant effect on the growth and yield of crops (Basu, M et al. 2009).

Temperature is the key climatic factor that matters the timing of biological processes and hence controls the developmental rate of many plants. Plants need a certain amount of heat to develop from one stage to another stage in their life cycles (Parthasarathi, Velu et al. 2013a.).

Therefore, the rising temperature and fluctuating rainfall patterns could adversely affect the productivity of crops (Berger and Turner, 2007). Farmers in northern Ethiopian highlands are affected by rainfall & temperature variability, drought, and climate risk. As coping mechanisms, the framers are trying to change sowing dates, crop varieties, for instant re-sowing early maturing cops like *"Saesa"* (early maturing local barley variety) or pulses. However, the decisions on the mechanisms varied from farmer to farmer and they are very subjective and depend on the farmer's individual knowledge and experiences. These lead not only to economic losses but also have an impact on moral condition of the farmers.

Therefore, characterizing the long term climate data and providing climate information for agricultural planning to minimize the yield reduction and economical loss caused by climate change and variability is crucial. Such analyses are very important for the future planning and decision-making process in the development and implementation of agricultural systems. Besides, it contributes to fill the gaps on scientific information in the agricultural sector of Ethiopia and Tigray region in particular. Thus, the present research study was carried out with the following objectives (a) to characterize rainfall and temperature (b) to determine the sowing date and length of growing period (c) to quantify evapotranspiration losses, and (d) to synthesise farmer's perception on climate change and variability.

2. Methodology

2.1 Description of the study area

The study area Kelte-AwelaloWoreda (Figure 1) is located at 13^0 49′ 43′′ latitude and $43^0$31′ 76′′ longitude of Tigray region, Northern Ethiopia. The average minimum and maximum temperature is 10 ^{0}C & 28^{0}C respectively and a total rainfall about 565 mm per annum.

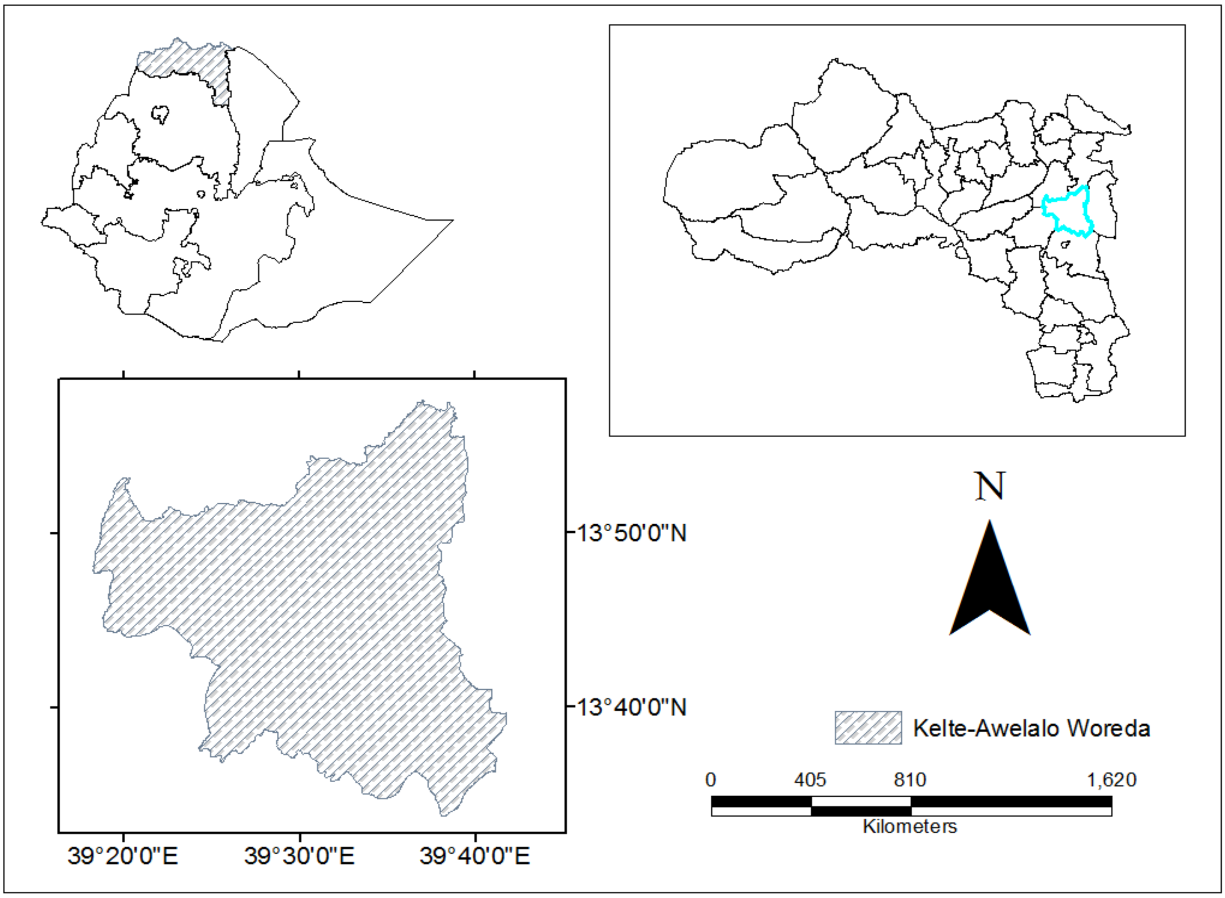

Figure1: Location of Kelte-Awelalo Woreda

Table 2: Descriptive statistics of Rainfall

Column	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Minimum	0	0	0	0	0	0	56.6	0	0	0	0	0
Maximum	4.9	11.3	79.6	79.6	83	135	415.5	409	102.6	35.4	27.6	9.8
Range	4.9	11.3	79.6	79.6	83	135	358.9	409	102.6	35.4	27.6	9.8
Mean	0.52	2.00	30.09	30.09	24.59	43.04	203.66	210.55	24.61	5.31	2.85	1.09
Std.	1.3	3.7	25.7	25.7	28.0	42.3	103.2	130.7	26.7	10.4	7.6	2.6
Median	0	0	23.65	23.65	13.9	27.4	177.05	215.05	18.35	0	0	0
CV (%)	251.60%	185.50%	85.40%	85.40%	113.70%	98.40%	50.70%	62.10%	108.70%	196.20%	265.90%	241.70%

The data used for the study was a long-term (historical) rainfall and temperature climate records. Prior to any analysis, the rainfall and temperature data sets were arranged using the Genstat Software. Once the data was arranged the detail analysis was done using the Instat software. Onset, offset, length of growing period and dry spell of rainfall was analyzed using Instat software assuming the following working definitions: (1) Onset of rainy season around Klete-Awlealo Woreda: any day after May15, when 20 mm of rainfall running over three consecutive days, as well as no dry spell longer than 7 days over the next 21 days from the onset season; (2) Offset of rainy season any day after 15 of September when soil water balance fall below half (50%). The soil water holding capacity was considered 100 mm/m. We considered the minimum threshold value of rainfall to be 0.85 mm below this amount considered as negligible amount of rainfall which means it was treated as part of dry spell. Then finally, we analyzed the dry spell, onset and offset of the rainfall.

Using Instat software Length of Growing Period (LGP) & Growth Degree Days (GDD) was analyzed. Moreover, Evapotranspiration & Effective rainfall was computed using CROPWAT 8.0 software.

To assess the farmers' perception on climate change (mainly rainfall and temperature) and their coping strategies, about, 60 farmers were interviewed using a semi-structured questionnaire that elicited information on type of crops grown, long term trend and change, production constraints as well as coping mechanisms. In this survey, three major crop species such as wheat, barley and finger millet were targeted. The analysis was done using the SPSS software.

3. Result and Discussion

3.1 Climate characterization

The rainfall was characterized as bimodal type of rainfall. The short rainy season from March to May locally called "Belg", and the longest one was from June to September locally called "Kiremt" had received the highest amount of rainfall from 203 to 210 mm, especially on the month of July and August. The "Bega" (dry) season from October to February had received around 35.4 mm.

The coefficient of variation (CV) had an inter-annual variability between the time series years and seasons as shown in Table 2. The CV was much higher (191% to 249%) in the dry season (October to January) locally called "Bega" than during February to May or "Belg" (with CV of 85% to 185%) followed with less (CV from 50% to 108%) in "Keremt" (June to September). This means that the rainfall variability in "Bega"was higher than "Belg"and"Kiremt. "Kiremt"is the main rainfall season for the region. This season is very useful for agricultural production and planning. Though the coefficient of variability of rainfall was comparatively lower in "Kiremt" than the other seasons, it had negative implication on yield reduction.

Upon the definition set for the study area the average rainfall onset was May19 followed by the early onset on May 4 & with the late onset on June 23 (Table 3).

And, the cessation of the season was ranged between 209 to 270 days, which corresponds to the Day of the year (DOY), July 27 and September 27 respectively. The early offset was July 27 and late offset was also September 27. The average offset of the rainfall was 219 of day of the year i.e. August 28 (Table 3). In some of the years rainfall starts early and small shower of rain that extends up to three to four days are common. Some of the farmers use this opportunity for land preparation. However, this situation is often followed by a long dry spell.

Even-though the rainfall starts early and ends on August28, there had rainfall variability between the years by CV of 50-108% and followed by large dry spell occurrence more than seven days over the main rainfall season. So the farmers have to wait until late June, the ideal planting period, particularly for wheat and barley. Nevertheless, finger millet growing farmers start planting when the onset of the rain commences as early as April or May and after that farmers shift to other cereals such as barley ("Hanfets"), wheat or maize.

The probability of dry spell at 7, 9 & 10 days showed on July (75%) & August (95%) of probability dry spell occurrences. The 7 days dry spell had high probability of dry spell than 9 & 10 days.

The onset and cessation date appeared influences the length of growing period. The length of growing period varied between 71 to 142 rainfall days. This range was the potential length of growing period for the crops. The average length of growing period was 100 rainfall days. The LGP appeared varied by 18.3% over the time series years (Table 3).

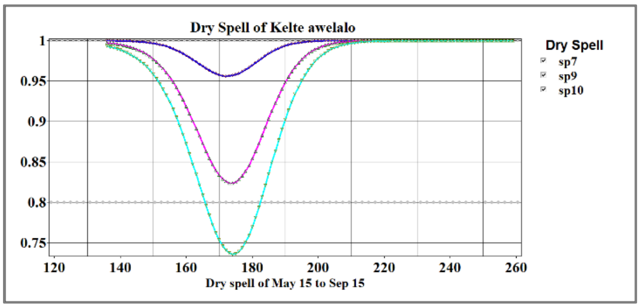

Figure 2: Probability occurrence of dry Spell

Table 3: Onset, Offset and Length of growing period

YEAR	Offset	Onset	LGP
1992	24-Aug	8-Jun	77
1993	6-Sep	18-Jun	80
1994	11-Sep	3-Jun	100
1995	16-Sep	19-May	120
1996	21-Aug	15-May	98
1997	11-Sep	19-Jun	84
1998	5-Aug	4-May	93
1999	29-Aug	14-May	107
2000	20-Aug	4-May	108
2001	5-Aug	9-May	88
2002	12-Aug	4-May	100
2003	27-Jul	11-May	77
2004	26-Sep	7-May	142
2005	6-Sep	8-May	121
2006	11-Sep	12-May	122
2007	22-Aug	14-May	100
2008	6-Sep	4-May	125
2009	28-Aug	25-May	95
2010	31-Aug	25-May	98
2011	2-Sep	23-Jun	71
2012	1-Sep	28-May	96

Temperature is also an important attribute that had an impact on climate change. The average maximum and minimum temperature was 28^{O}C and 11^{O}C respectively. As shown in Figure3 the highest temperature was observed during May (29^{O}C) and June (30^{O}C) respectively. The minimum temperature record was attributed to December (8^{O}C) and January (7^{O}C) and both months were dry and free of substantial rain.

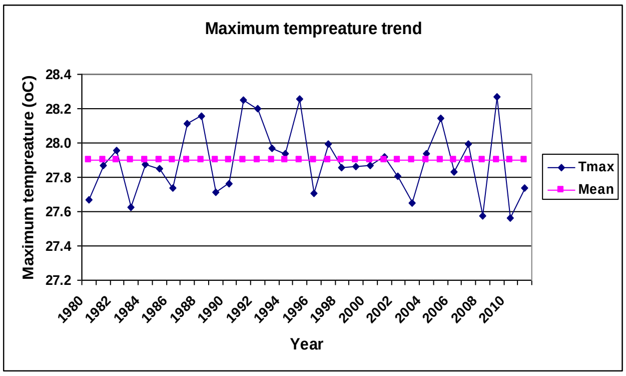

Figure 3: Maximum temperature of Kelte-Awelalo Woreda

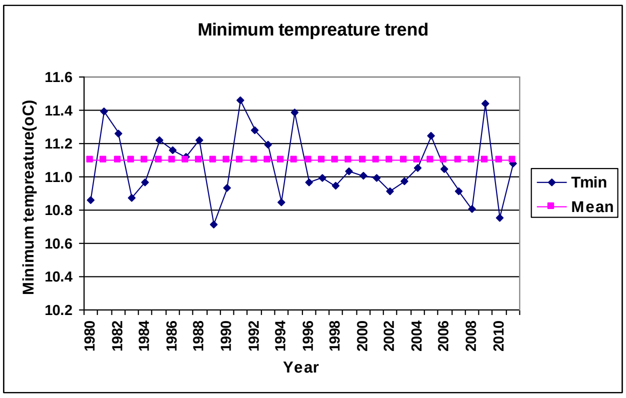

Figure 4: Minimum temperature of Kelte-Awelalo Woreda

Crops use the temperature as heat for their developmental growth at different stages. The standard agronomic approach involves converting daily temperatures into degree days, which represent heating units accounting for such non linearity. (Hodges and Grierson 1991).

The result showed the cumulative growth degree days (GDD) was 623^{O}c during grain-filling stage. This high cumulative heat indicated that the crop species in the area had experienced daily temperature extremes and apparent heat stress. The CV of the time series years of the study area showed that there had variation of 57% heat temperature resulted from existing temperature variability (Table 4).

Table 4: Descriptive Statistics of Growth Degree Days (GDD)

Descriptive Statistics of GDD	
Minimum	19.3
Maximum	623.3
Range	604
Mean	321.6
Std.	182.86
Median	322.05
CV (%)	56.90%

Change in temperature had also an impact on evapotranspiration loss. The mean monthly evapotranspiration rate was ranged between 123 to 170 mm/month (Figure 5). Minimum monthly evaporation was occurred during December (123.3 mm) and this was may be linked to the frequently observed minimum temperature during this period of the year. Evaporation was quite high in May (165.6 mm/month) and June (170.7 mm/month) resulted from high air temperature. The high evapotranspiration loss and limited moisture at the root zone of the crops often happened during May and June may warrant supplementary irrigation to improve the livelihood of the most venerable people - small scale farmers (Figure5).

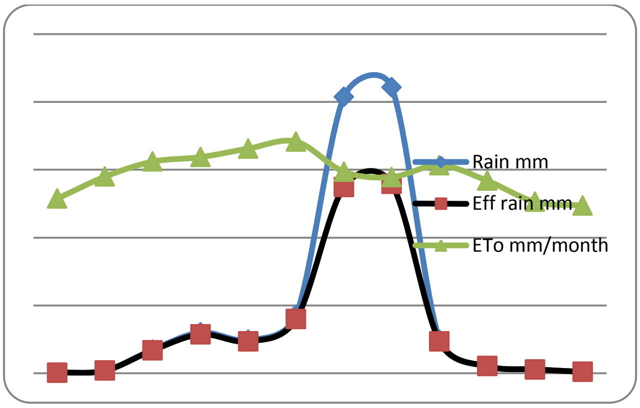

Figure5: Comparison between monthly rainfall, effective rainfall and evapotranspiration

3.2 Farmers perception on climate change and variability

All respondents confirmed that they had already affected by climate change. They explained the climate change in terms of climate attributes.

About 91% of the respondents felt an increasing temperature and 100% of the respondent noted a decreasing precipitation pattern. Similarly 82% of the respondent also noticed recurrent drought resulted from hanging rainfall pattern. Frost and disease/pest incidence are additional phenomenon that 87 % and 78% of the respondent respectively have observed due to climate change as shown in Table 5. The interviewed farmers' stressed that there is declining of agricultural yield from time to time due to the climate change.

Table 5: Farmers perception on climate change

Climate Change Description	percent
Disease/Pest incidence	78%
Frost	87%
Frequency of drought	82%
Changing time of rain	100%
Decreasing Precipitation	100%
Decreasing temperature	0%
Increasing temperature	91%

Therefore, the farmers used different adaptation mechanisms to avert the negative impacts of the climate change. The major adaptation strategies that were practiced by farmers were off-farm activities (by 52% of the respondents), supplementary irrigation (43%), soil and water conservation (18%), use of early maturing variety (26%), changing crop type (30%) and crop diversification (13%) as shown in Table 6.

Table 6: Adaptation mechanisms against climate change and variability

Adaptation mechanisms	Percent
Soil and Water Conservation	17%
Species change	30%
Crop Diversification	13%
Off-farm Job	52%
Access to irrigation	43%
Short season Variety	26%

Due to climate change and other related factors most of the respondents confirmed that annual crop yield harvested from their own farm was not quite enough to cover their annual household consumption. One season production can only be enough for only five months on average. The remaining months were covered by involving in off-farm and other activities.

Conclusions and Recommendations

The current study illustrated that daily basis long-term climate data characterization would provide an insight in designing proper agricultural practices and identification of optimum sowing date as a strategy to minimize crop failure and yield reduction. This approach could be very useful in obtaining valuable climate and agronomic information for different decisions.

The interviewed farmers indicated that they often encountered frequent drought, frost, diseases, variability of rainfall and temperature. This can be mainly due to climate variability and other additional factors too. The long-term analysis of rainfall showed that the seasons had high inter-seasonal variability between the time series of the years. The coefficient of variation (CV %) was much higher in the "*Bega*" (October to January) season ranged between 191% to 249 % than in the "*Belge*" (February to May) 85% to 185% and the main rain season, "*Kiremt*" (June to September) 50 to 108%. This showed that agriculture is a climate sensitive livelihood strategy, despite its potential to create jobs for about 85% of the population in the country and even more in the study area. The high degree of rainfall variability observed in the current study may high negative implication on crop production and livelihood of the farming community in general.

The long-term rainfall trend showed that the average onset was on May19, which had an offset on August 28. The seasons had a large probability of dry spell on July (75% probability) and August (95% probability). Moreover, the average length of growing period during the main season (''*Kiremt*'') was estimated to be 100 rainy days, having a long dry spell occurrence for more than 7 days.

In addition, temperature is also the other factor that contributes a lot to the climate variability and change as well as to crop development. Furthermore, the cumulative Growth Degree Days (GDD) result showed that heat temperature 623^0c. This high cumulative heat indicated that the crop species in the area had experienced daily temperature extremes and apparent heat stress. Corresponding with this temperature had also an impact on evaporation loss. The mean monthly evaporation rate was 123 to 170 mm/month. The increasing trend of temperature has appeared to induce high loss of moisture *via* elevated evaporation and its impact was largely magnified during May and June. Based on the climate data analysis and the present climate scenario, the optimal planting data for finger millet would be as of mid-May but for wheat, barley and “Hanfets” (mixture of wheat and barley) may be on mid-June to the first week of July.

Minimizing the risks of crop failure and ensure food security that can happen due to climate variability is possible by integrating those indigenous and scientific knowledge, such as sowing the crops on the right time and by exercising different climate change adaptation mechanisms.Climate risk analysis and weather forecast information is very useful for agricultural planning and production of farmers and decision makers.

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