Rainfall Variability and Trends Analysis in the Sorghum Growing Semi-Arid Rift Valley of Ethiopia

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Abstract

*In Ethiopia, 60% of the land is covered by sorghum, and the climate affects the major producing regions.*The objective of this work was to assess variability and trends of rainfall in the semi-arid Rift Valley of Ethiopia. 40 years of rainfall data were analyzed for 11 stations. The selected parameters were analyzed for rainfall variability and trend analysis was performed following Mann–Kendall methods. The start and end of the growing season, length of the growing period, and dry spells were analyzed for the stations. The results showed in all the locations was the highest mean monthly rainfall recorded in July, and August then followed by September. Compared to the longest rainy period (*52.3–70.8%*), the short rainy period (*19.4–33.2%*) contributes less rainfall to the annual rainfall which was also associated with high inter-seasonal variability (CV ranged from 31.5 to 88%) short rain season. PCI value in studied regions in all stations showed the existence of high concentration in seasonal rainfall distribution. *Sen's slope for NRVE, ERVE, and CRV increases by 0.02-0.81, 0.05-0.71, and 0.02-0.81 mm/yr. in September. Rainfall from 0.31-2.76 mm/yr. decreases to a 0.19-5.12 mm/yr increase in the short and main seasons. Rainfall has increased in some stations (from 0.042 to 3.88 mm/yr.) but decreased in five stations (1.29 to 3.71 mm/yr.). Stations with different rainfall onset and CV (4.9%–16.6%) have varying rainy seasons (24 to 200 days), which affect crop yield. Longer periods lower the risk; it rains every 90 days for crops. Optimize management based on LGP and rainfall variations at stations. Climate change risks crop yields. Consider early crops and rainwater collection*.

Keywords; Climate variability and trend, start of the season, LGP, dry spell.

1. Introduction

Climate variability and change constitute paramount and consequential issues that currently confront the world (Parry et al., 2007; Murtaza et al., 2019). These phenomena are ubiquitous and have extensive implications worldwide (Shafer, 2017). Significantly, climate variability and change have been instigated by either anthropogenic activities or natural phenomena (Saroar, 2016). The influence of anthropogenic climate variability and change on climate extremes has become increasingly apparent on a global scale, as noted by the Intergovernmental Panel on Climate Change (IPCC, 2021). The correlation between anthropogenic climate alteration and the irregularity of rainfall amounts and patterns in sub-Saharan Africa remains uncertain, most notably within the area of East Africa as noted by the UNDP in 2018. The locality is presently under an imminent risk posed by disparities in climate and its irregularities, such as periods of drought and inundation, which in certain instances have resulted in considerable economic and social impacts (USAID, 2015). The study conducted by UNDP (2018) and Sonwa et al. (2017) highlighted the observed alterations in precipitation patterns and trends within the region of eastern Africa. This phenomenon was further substantiated by the detection of interannual variability in the onset, cessation, and duration of seasonal rainfall intervals, number of rainy days, dry spell frequencies, and rainfall intensity (Sonwa et al., 2017; UNDP, 2018; NAP, 2019). According to the FAO's report in 2011, the issue pertaining to food security continues to be a prominent concern in the supposed region. The country of Ethiopia currently faces a critical situation, as it has been identified as the most susceptible nation to climate variability and change (Sonwa et al., 2017; NAP, 2019). This susceptibility is largely attributed to the country's heavy reliance on rain-fed agriculture and natural resources, as has been noted in previous studies (Schlenker and Lobell, 2010; Gebreegziabher et al., 2011; IMF, 2020; World Bank, 2020), coupled with its limited ability to adapt to and effectively manage these anticipated climatic shifts (Schlenker and Lobell, 2010; World Bank, 2020).

In recent years, there has been a notable interest in the examination rainfall variability and trend analysis across various spatiotemporal scales, in light of the scientific community's rigorous focus on climate change concerns at both global and regional level (Hulme, 2011a; Castán, 2020; Hulme, 2020). The comprehension of rainfall occurrences and amounts in a specific spatial and temporal context largely rests on the evaluation of rainfall fluctuations and patterns, as posited by Ngetich et al,(2014). Examination of the seasonal patterns of rainfall has persistently garnered significant attention in comprehending its diverse components, such as amount of rainfall, rainy days frequency, cropping season duration, and dry intervals frequency (Ngetich et al., 2014). Furthermore, attention has been directed towards start and end of the respective seasons (Kassie et al., 2013; Bekele et al., 2016; Edao et al., 2018). The subject of past climate variability and change is widely recognized as a significant factor affecting food security. This is primarily attributed to alterations in the amount and interannual variability of rainfall, often leading to recurrent droughts and floods (Mbow et al., 2019; IPCC, 2019, 2021). Notably, rainfall is frequently employed as a key measure of climatic variability and its resultant impacts (Maharjan and Joshi, 2013). Abera's (2022) research indicates that variations in rainfall, specifically during the primary and shorter rainy periods, exert a substantial influence on the yield of sorghum in Ethiopia. According to a study conducted by Ejeh and Ikpe (2022) in Nigeria, it was found that a significant proportion of the variation in sorghum yield, estimated at 36.4%, was attributed to the variability observed in rainfall patterns.

From the perspective of crop production, another crucial aspect of rainfall that must be taken into consideration is the level of variability observed in the length of the growing period (LGP) (Solomon et al., 2015; Edao et al., 2018) as well as the frequency of rainy days (Mugalavai et al., 2008; Wagaye and Eshetu, 2021).

Several studies highlight the impact of interannual and interseason rainfall variability on crop productivity in Ethiopia. Specifically, factors such as the late start and early end of the season, length of growing period, and dry spell during the main rain season have been found to have significant implications for crop yield. Various studies have identified this phenomenon in the semi-arid rift valley of Ethiopia (Araya and Stroosnijder, 2011; Mahoo et al., 2013; EPCC, 2015; Alemayehu and Bewket, 2016), particularly with respect to the early end of rain and associated high temperature, which can lead to reduced grain filling and yield (Shah and Paulsen, 2003; Segele and Lamb, 2005). The availability of water for crops is a pivotal factor, as it is largely influenced by the timing, duration, and end of rainfall, which ultimately determine whether a farming season is successful or not (Araya and Stroosnijder, 2011; Ngetich et al., 2014). As per the study conducted by Rae et al. (2004), the early onset of the rainy season stimulates crop germination, as a majority of farmers tend to sow their crops in arid soils. For the purposes of this investigation, the term "onset of the rainy season" denotes the initiation of the growing season for crops. It noteworthy that the specific aspect referred to as the "false onset of the rainy season" has been identified, which pertains to an event characterized by a period of drought preceding the typical onset of the rainy season (Dunning et al., 2016). In instances of an extended period of aridity, the seedlings experience an abortive initiation and consequently succumb, mandating their transfer to an alternative location (Ati et al., 2002; Rae et al., 2004; Kipkoric et al., 2007). As per the findings of a study in Nigeria by Ati et al., 2002, conventional approaches for determining start dates were evaluated. The previously established methodologies for minimizing false starts, as observed by scholars , have been deemed inadequate. Therefore, alternative approaches that effectively reduce erroneous instances are deemed necessary. Segele and Lamb (2005) suggest that agricultural failure in Ethiopia's semi-arid rift valley can primarily be attributed to recurrent 10-day dry spells and a shortened growing season that results from either replanting or untimely rain patterns, such as early cessation or late arrival of the monsoon. The optimization of agricultural productivity metrics in semi-arid regions can be facilitated through dependable predictions concerning the start, cessation, and duration of the growing season. (Mugalavai et al., 2008). Through the provision of pertinent information, recommendations pertaining to optimal seed and fertilizer rates, alongside plant thinning protocols, were facilitated, enabling sensible forecasting of production with the aim of effective planning. The climatic conditions of Ethiopia are highly susceptible to rainfall variability, with current studies identifying it as the foremost threat in terms of both magnitude and frequency. Such variability manifests in a host of ways, ranging from delayed onset or premature cessation of showers, periodic rainfall deficits, prolonged droughts, and occasionally complete forfeiture of the entirety of the rainy season (Conway and Schipper, 2011; Aberra, 2012). The consequences of this phenomenon have deleterious impacts on rainfed agriculture that prevails in the environment, food security, as well as a multitude of ecological processes, as affirmed by Demeke et al. (2011) and Di Falco et al. (2012).

The region of East Africa is primarily affected by rainfall variability, which constitutes a crucial element in both climate and weather. The intensity of this variability is known to fluctuate within the region, contingent upon the ecological context of the respective Ethiopia. This observation has been corroborated by researchers such as Dinku et al. (2008), Demeke et al. (2011), and Omondi (2016). The variation of precipitation patterns exhibits dissimilar dimensions across diverse regions of Ethiopia (USAID,2015). The variability in rainfall is a fundamental characteristic of the climate in Ethiopia's arid and semiarid regions, as noted by Girma (2005). It has been reported by Selezi and Zanke (2004) and Tilahun (2006) that Ethiopia has undergone notable alterations taken together seasonal and yearly precipitation levels and the frequency of wet days. The present study aims to examine the variability of rainfall in different regions of Ethiopia by reviewing the relevant literature. Notably, Kassie et al. (2013) reported high inter-seasonal variability in central the Rift Valley of Ethiopia, while Araro et al. (2019), Belay et al. (2021), and Teshome et al. (2022) found high variability of rainfall both interannually and inter-seasonally in the eastern and southern parts of the country. Conversely, Ayalew et al. (2012), Hadgu et al. (2013), Asfaw et al. (2018), and Wagaye and Antensay (2020) observed significant variability of rainfall in the northern and northwest parts of Ethiopia.

The variations in rainfall patterns over the earlier half-century exhibit less observable in comparison with temperature. However, East Africa has undergone a considerable variety of alterations in both the distribution and amount of rainfall (Few et al., 2012). Several localities have experienced variations in rainfall wherein some have observed an increase in certain seasons while others have witnessed a decline. However, identifying general patterns of rainfall has proven to be elusive and arduous, as asserted by Daron (2014) and Few et al. (2012). The issue of utmost importance pertains to the intricate and significant interannual and interdecadal variations in the level of rainfall experienced in Ethiopia, as asserted by the Ministry of Environment and Forests in 2015. Nevertheless, an obvious decline in precipitation levels and an apparent year-on-year fluctuation of rainfall have been observed (Ministry of Environment and Forest, 2015; World Bank, 2020), characterized by distinct disparities in the distribution of rainfall occurrences among various territories within Ethiopia. According to a report by the United States Agency for International Development (USAID) in 2016, certain areas have experienced a notable decline in rainfall, with the country's south-central region being particularly affected. Various trend analysis studies have been conducted regarding regional and temporal dimensions within Ethiopia, resulting in diverse findings (Wing et al., 2008).According to Teshome et al. (2022), there is an insignificant declining trend in the annual and short rainy seasons of eastern Ethiopia, whereas there is observable upward trend in the main rainy season. In the studies by Hadgu et al. (2013) and Gebreegziabher et al. (2011), a study conducted in northern Ethiopia indicated the presence of rainfall trends that were both upward and downward. On the other hand, findings from a study carried out in southern Ethiopia revealed a notable increase in yearly rainfall levels during both main and short rainy periods (Belay et al., 2021). In the Southwest (Cheung et al., 2008) and Central Rift Valley (Cheung et al., 2008; Bekele et al., 2017) of Ethiopia, a trend study of annual and seasonal rainfall revealed a considerable decline over a considerable period. Several research studies have indicated a decrease in precipitation levels during both short and main rainy seasons in specific areas across the southern, southeastern, and southwest regions of Ethiopia, spanning from 1970 to the late 2000s (Funk et al., 2012).

The detrimental impacts of pronounced seasonality and variations in precipitation patterns on crop production have impeded economic progress in Ethiopia, as posited by You and Ringler (2010). The evaluation of precipitation irregularities and patterns utilizing past records is crucial in comprehending the challenges associated with drought, floods, and various water consumption practices (Ngetich et al., 2014; Mugalavai et al., 2008). The central rift valley (CRV) and semi-arid rift valley escapements of Ethiopia hold immense significance as a vital region for food production. However, this region is susceptible to drought owing to variations in rainfall patterns, leading to negative effects on the farming community's agricultural productivity (USAID, 2016b). The production of sorghum, cultivated in semi-arid areas that experience significant climatic variability, is considered as the principal crop to guarantee food security in Ethiopia, based on the data provided by the Food and Agriculture Organization's statistics (FAOSTAT, 2015). Sorghum, a cereal crop, holds significant importance in Ethiopia as it accounts for a significant portion (more than 60%) of the cultivated land (ATA, 2015;EIAR, 2020). However, the producing regions are susceptible to the effects of climate variability, resulting in notable impacts on the growth and yield of sorghum (Clare et al., 2019; Eshetu et al., 2020). Undoubtedly, comprehending the climatic components, specifically, the rainfall pattern, can serve as an indispensable tool in devising effective strategic frameworks and pragmatic planning geared towards enhancing the socioeconomic welfare of a significant cohort of agricultural practitioners in the semi-arid region of the Rift Valley (CRV). Consequently, this investigation was instigated to assess the variability and trend of rainfall in the semi-arid Rift Valley of Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the study areas

The prominent geological feature of the Main Rift Valley in Ethiopia is characterized by its intricate terrain, which is marked by noteworthy tectonic escarpments that demarcate the rift floor from the adjacent plateaus. A visual representation of this phenomenon can be observed in Figure 1, while further details can be gleaned from Table 1. According to Corti (2013), this area is situated between the topographical elevations of the Ethiopian and Somali Plateaus. According to Keir et al. (2005) and Agostini et al. (2010), it is presently postulated that the faults situated in the northern Rift valley escarpment are in a state of quiescence. However, in the southern region, they are expected to remain tectonically and seismically active. The Ethiopian highlands are a notable geographical feature, resulting from the formation of the Main Rift Valley on either flank, as observed by Agostini et al. (2010).

This study focuses on the semi-arid rift valley of Ethiopia, which is located from 38o.07'–41o.11` E and 7o.85'–12o.42` N. It includes the heart and corridor of the Ethiopian Rift Valley, stretching from the Afar Triangle in the north to the Chew Bahir in the south, and encompasses semi-arid lowlands in the northwest and eastern areas. The CRV has a central valley floor at 1500-1700m a.s.l. and is flanked by northern, western, and eastern escarpments exceeding 4000m a.s.l. (Jansen et al. 2007). Lowland areas of the rift valley have varying climates, from semi-arid to humid. The CRV has a weak bi-modal rainfall pattern, typical for the central, eastern, and northern parts of Ethiopia. Valley floor gets 175-358 mm rain in the short season (Mar-May) and 420-680 mm in the main season (Jun-Sep). Eastern & northern rift valleys get 833 mm in the main season and 603 mm in the short season annually.. Andosol (orthic) is the most dominant soil, followed by phaeozems (ortic) and chromic luvisols (orthic) (FAO, 1984), due to the prevalence of silt and ash (white, volcanic) with high water infiltration capacity. Due to agriculture and dense population, the flora is scarce, causing soil erosion in sloping areas with andosols.

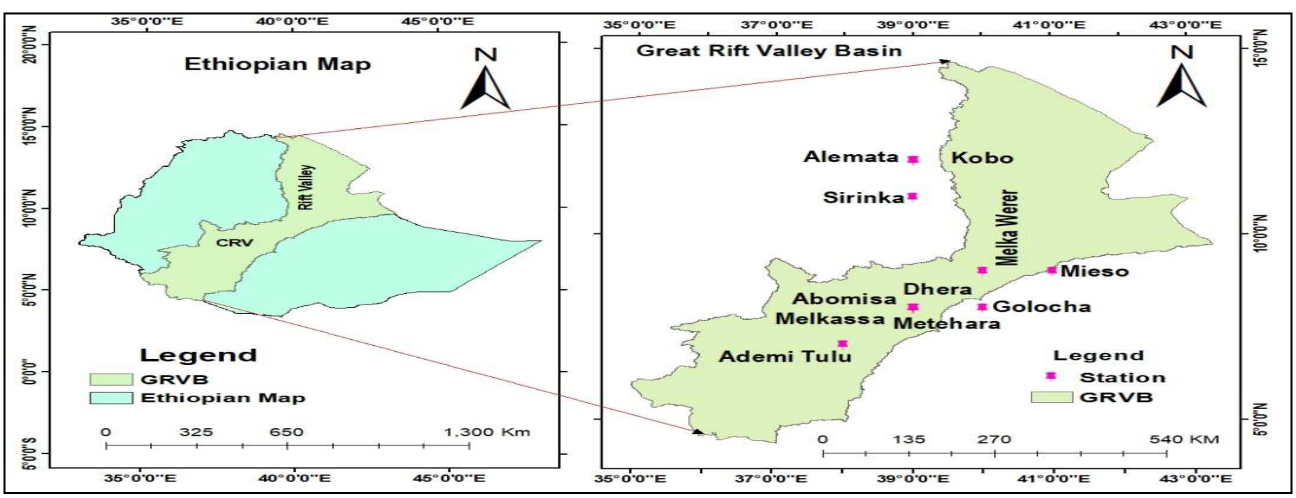


Figure 1: Study areas

Rainfed cereal production and limited livestock rearing support households in semi-arid rift valley. High rainfall variability and drought cause crop failure and famine in the central and eastern rift valley (Kassie et al., 2014; Getent and Alister, 2012). The region is a significant land portion of the country that is environmentally vulnerable to climate change (Kassie et al., 2013; Hadgu et al., 2013; Muluneh, 2017). Cereals, including teff, maize, sorghum, common beans, and wheat are the main crops. Past rainfall was analyzed for eleven stations in the CRV floor and its semi-arid escapements. Studied areas: CRV floor (Adami Tullu, Melkassa, Dhera, Matahara, Mieso, Melka Werer), Easter RV escapement (Abomsa, Gololcha), and northern RV escapement (Kobo, Sirinka, Alamata). All known for sorghum production and similar weather.

2.2. Type and source of meteorological data

The Enhancing National Climate Services (ENACTS) dataset was used as a source of rainfall data. The ENACTS initiative reconstructs rainfall data by combining station weather data with the satellite rainfall estimates. Bias correction factors are applied to the satellite records to develop a spatiotemporally complete dataset from 1981 to 2018 at a high spatial resolution (i.e, about 4 x k km grid) (Dinku et al., 2016). The information was thoroughly assessed, and evaluations at stations around the nation showed the data to function well (Alemayehu and Bewket, 2017a; Dinku et al., 2016). ENACTS data for 11 locations in the semi-arid rift valley were provided for the current investigation by the Ethiopian National Meteorological Agency. Because enacted stations are few and do not cover all research sites (Alemayehu and Bewket, 2017a), and station datasets frequently have missing values, ENACTS data was chosen for the analysis (Asfaw et al., 2018).

Table 1. Geographical location and the respective period of the rainfall database were used for climatic analyses of the targeted meteorological stations in the three regions of Ethiopia.

Regions	Station	Latitude (^{0}N)	Longitude (^{0} E)	Elevation (m)	Database periods	Rainfall
Central Rift valley floor	Adami Tullu	7^{0}.85”	38°.07”	1630	1981-2021	Yes
	Melkassa	8.24°	39.19°	1550	1981-2021	Yes
	Dheera	8^{0}.33”	39^{0}.32”	1741	1981-2021	Yes
	Metehare	8^{0}.85”	39^{0}.9”	944	1981-2021	Yes
	Abomisa	8^{0}.46”	39^{0}.83”	1630	1981-2021	Yes
	Malka Werer	9^{0}.4”	40^{0}.07”	750	1981-2021	Yes
Eastern RV escapement	Gololcha	8^{0}.25”	40^{0}.125”	1373	1981-2021	Yes
	Mieso	9^{0}.2”	41^{0}.11”	1470	1981-2021	Yes
Northern RV escarpment	Kobo	12°15\`	39°38\`	1468	1981-2021	Yes
	Sirinka	11°80′	39°31′	1850	1981-2021	Yes
	Alamata	12^{0}.42”	39°63\`	1589	1981-2021	Yes

2.3. Data quality check and preassessment

After the database construction, quality control of the rainfall data was first performed by checking for outliers and temporal homogeneity.

Outlier detection: The Tukey fence is used to outline the values greater or lower than a threshold value of specific time series data that can affect the detection of homogeneity (Gonzalez-Hidalgo et al., 2009). It is the data range corresponding to**:**

$$[Q1 - 1.5 * IQR, Q3 + 1.5 * IQR] \quad (1)$$

where Q1 and Q3 are, respectively, the lower and upper quartile points, 1.5 is the standard deviation from the mean, and IQR is the interquartile range. Values outside the Turkey fence are considered outliers. In this study, such outliers were set to a limit value corresponding to ±1.5×IQR.

Homogeneity test: In this study, due to its lower demand in application and interpretation as well as the cumulative deviation test used for absolute testing (using station's data), this method is commonly used in climatology to detect homogeneity in meteorological time series (Ngongondo et al., 2011; Kang and Yusof, 2012). It is noted that tests for homogeneity can be based on the adjusted partial sums or cumulative deviations from the mean, and it is given as follows**:**

$$\int_0^* = 0 \text{ and } \int_k^* = \sum_{i=1}^{k} (Yi - \bar{y}) \text{ k=1,…..n} \quad (2)$$

The term $\int_k^*$ is the partial sum of the given series. If there is no significant change in the mean, the difference between yi and $\bar{y}$ will fluctuate around zero. The significance of the change in the mean calculated with 'rescaled adjusted range' R, which is the difference between the maximum and the minimum of ∫values scaled by the sample standard deviation as**:**

$$R = (\max \int_{0 \le k \le n}^* k \text{ -min} \int_{0 \le k \le n}^*)/ \quad \text{SD} \quad (3)$$

Then the critical value for R/n is calculated by Buishand (1982) and for n=30 its value is 1.5 and 1.4, respectively, for 5% and 10% probability levels**.**

Test of randomness and persistence: In this study, before proceeding with trend analysis, the time series data were tested for randomness and independence using the autocorrelation function (r1) as described in Jenkins (1976) in the following manner;

$$r1 = \frac{\sum_{i=1}^{n=1} (Xi - X)(Xi + 1 - X)}{\sum_{i=1}^{n} (xi - x)} (4) \quad (4)$$

Where an observation, xi+1 is the following observation, $x^{-}$is the mean of the time series, and n is the number of data. In addition, we defined the critical region at 5% probability as follows;

$$\left[(-1 - 1.96\sqrt{(n-2)}/(n-1), (-1 + 1.96\sqrt{(n-2)}/(n-1)\right] \quad (5)$$

Serial correlation of lag^{-1} (the correlation of two consecutive observations in the time series data) was employed in this study. Whenever a significant correlation appeared in the data series, the data series has been 'pre-whitened' following the procedure described by Partal and Kahya (2006). The pre-whitened data series may obtain as;

$$(X2 - r1X1, X3 - r1X2 \ldots\ldots Xn - rnXn - 1) \quad (6)$$

2.4. Variability analysis

The temporal variability occurrence of various rainfall indices was assessed at the selected eleven weather stations in its region based on the analysis of a set of indicators defining variation following Stern et al. (1982), Trnka et al. (2011), and Vergni and Todisco (2011). Precipitation Concentration Index (PCI), Standardized Rainfall Anomaly (SRA), and coefficient of variation (CV) were used as descriptors of annual and seasonal rainfall variability over historical periods.

The coefficient of variation (CV%) is used to assess the variability of rainfall data relative to its standard deviation and is normally presented as a percentage.;

$$CV\% = \frac{\delta}{X} * 100 \quad (7)$$

Where CV is the coefficient of variation in percent, δ and x are the mean and standard deviation values, respectively. The degree of variability in rainfall is classified as less (CV<20%), moderate (CV=20% to 30%), and highly variable (CV>30%) according to the estimated CV values (Alemu, and Bawoke (2019).

The precipitation concentration index (PCI) was used for characterizing the monthly rainfall distribution and was analyzed using the formula described by De Lu'set et al. (1999, 2011) as;

$$\text{PCI annual}=100* \left[\frac{\sum Pi\ 2}{(\sum Pi)2}\right] \quad (8)$$

$$\text{PCI monthly}=33.3* \left[\frac{\sum Pi\ 2}{(\sum Pi)2}\right] \quad (9)$$

Where: Pi is the rainfall amount of the month. According to Oliver (1980), PCI values of less than 10 indicate a uniform monthly distribution of rainfall, values between 11 and 20 indicate high concentration, and values above 21 indicate very high concentrations. Inter-annual fluctuations were evaluated by calculating standardized rainfall anomalies (SRA) and graphically presenting the results.

The standardized anomaly index (SAI); was calculated to examine the nature of the variability and enable the determination of the dry and wet years in the record as follows**:**

$$SAI = \frac{Pt - Pm}{\partial} \qquad (10)$$

Where SAI is the standardizing anomaly index during a year (or season); Pt is the annual rainfall in year t; Pm is long-term mean annual rainfall throughout the observation; and δ is the standard deviation of annual rainfall throughout the observation. Positive standardized rainfall anomalies indicate greater than long-term mean rainfall, while negative anomalies indicate less than the mean rainfall. When averaged over several stations, the normalized rainfall anomaly yields a normalized rainfall anomaly index. The drought severity classes are extreme drought (SRA<-1.65), Severe drought (-1.28>SRA>-1.65), moderate drought (-0.84>SRA>-1.28), and no drought (SRA>-0.84).

2.5. Trend analysis

The Mann-Kendall (MK) test is an Excel template of a non-parametric approach widely applied in various trend detection studies like rainfall (Karaburun et al., 2011). The variance of S for the situation where there may be ties (i.e., equal values) in the x values is given by**:**

$$var(S) = \frac{1}{18}\left|N(N-1)(2N+5) - \sum_{i=1}^{M} ti(ti-1)(2ti+5)\right| \qquad (11)$$

Where: m is the number of tied groups in the data set and $ti$is the number of data points in the ith tied group. For n larger than 10, ZMK approximates the standard normal distribution (Partal and Kahya, 2006; Yenigunet al., 2008) and is computed as follows;

For n larger than 10, the standard normal Z statistic will be used and is computed from equation 12 as;

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{\mathrm{var}(s)}} & if s > 0 \\ 0 & if s = 0 \\ \dfrac{s+1}{\sqrt{\mathrm{var}(s)}} & if s < 0 \end{cases} \qquad (12)$$

The presence of a statistically significant trend is evaluated using the Z value. A positive or negative value of Z indicates an upward or downward trend. The statistic Z has a normal distribution. In a two-sided test for trend, the null hypothesis Ho should be accepted if $|ZMK| < Z1{-}\alpha 2$ at a given level of significance. $Z1{-}\alpha\ 2$ is the critical value of ZMK from the standard normal table. e.g., for a 5% significance level, the value of $Z1{-}\alpha\ 2$ is 1.96.

Sen's estimator of the slope*;* it is used to estimate the magnitude of an existing trend (as a change per year). Sen's method can be used in cases where the trend can be assumed to be linear. This method could be used with missing data and remain unaffected by outliers or gross errors (Karpouzoset et al., 2010). Then, the slope magnitude (change per unit time) was estimated for rainfall as below;

$$Q = Q_{\frac{N+1}{2}} \qquad \text{if } N \text{ is odd number} \qquad (13)$$

$$Q = \frac{1}{2}\left(Q_{\left(\frac{N}{2}\right)} + Q_{\left[\frac{N+2}{2}\right]}\right) \qquad \text{if } N \text{ is even} \qquad (14)$$

2.6. Analysis of the growing season

2.6.1. Analysis of start, end, and length of growing periods

The Start (SOS) and end of the growing season (EOS) analysis of seasonal climate characteristics for the start and end of the season were explored for the main growing (June to September) rainy season using historical data. The criterion used in this study was a rainfall of 20 mm or more accumulated over three consecutive rainy days after a specified date (in this case, June 1) with no dry spell greater than 9 days in the next 21 days (Girma, 2005; Liben, 2013; Edao et al., 2018). SOS was calculated from Equation (15), given by;

$$\boldsymbol{SOS = D\frac{(20-F)}{R}} \qquad (15)$$

Where; SOS is the start date and *D* is the total number of days in the first month with effective rain (MER: accumulated rainfall totals equals or exceeds 20 mm). *F* (mm) is the accumulated rainfall total of earlier months and R is the accumulated rainfall within the MER.

Moreover, the end of the season (EOS) was defined as the date when the available soil water content dropped to 10 mm m-1 of available water (Dodd and Jollite, 2001; Tesfaye and Walker, 2004; Girma, 2005; Liben, 2013; Edao et al., 2018) in October. Rainfall and dates were also calculated using Equation (16), given by;

$$\boldsymbol{EOS = b + 275} \qquad (16)$$

Where EOS is the cessation date and is defined in equation (16) as any day from 1st October after which there are more than 7 consecutive days of rainfall with amounts below 50% of the soil water requirement and "by" denotes the number of days in which there is maximum build-up of pre-season moisture.

The Length of the growing period (LGP) is a key factor in deciding the maturity of cultivars to be grown in dissimilar rainfall regimes. Therefore, LGP is considered the period from the SOS to the EOS. It was calculated by subtracting the date of the beginning of the rainy season from the date of the end of the growing season in October (Mupangwa et al., 2013; Mensah et al., 2016). The length of the growing period (LGP) is the difference between the end and the onset, which is expressed as equation (17)**;**

$$LGP = EOS - SOS + 1 \quad (17)$$

Number of rainy days: based on the definition of the National Meteorological Agency of Ethiopia, a day is considered a rainy day if it accumulates 1mm or more rainfall (NMA, 2001). The number of rainy days was, therefore, counted starting from the first day of June to September 30 (main season) in each year. Moreover, the maximum number of consecutive dry days (a day that accumulates rainfall of 1 mm) was counted to determine the dry spell length in the main growing season**.**

2.6.2. Analysis of the probability of dry spell occurrence

For each meteorological station, the daily rainfall data were fitted to a simple Markov chain model. The chance of rain was assessed both when the previous day was dry, i.e., the chance that a dry spell would continue, and when the previous day was rainy, i.e., the chance that a rainy spell would continue, which is known as a Markov chain (Stern and Cooper, 2011; Stern et al., 2006). The probability of dry spell lengths of 5, 7, 10, and 15 days during the main growing season was determined using the Markov chain model to obtain an overview of dry spell risks during the crop growing season and provide a viable decision aid to various practitioners. Dry spell lengths of 5 to 15 days were selected to accommodate both drought-sensitive and drought-tolerant cultivars during the growing season. The following expressions were used in the Markov chain analysis of dry spells in the study area (Reddy et al., 1990):

$$Pd = \frac{Fd}{n} \quad (18)$$

$$Pdd = \frac{Fdd}{Fd} \quad (19)$$

$$Pwd = 1 - Pdd \quad (20)$$

$$Pdw = 1 - Pww \quad (21)$$

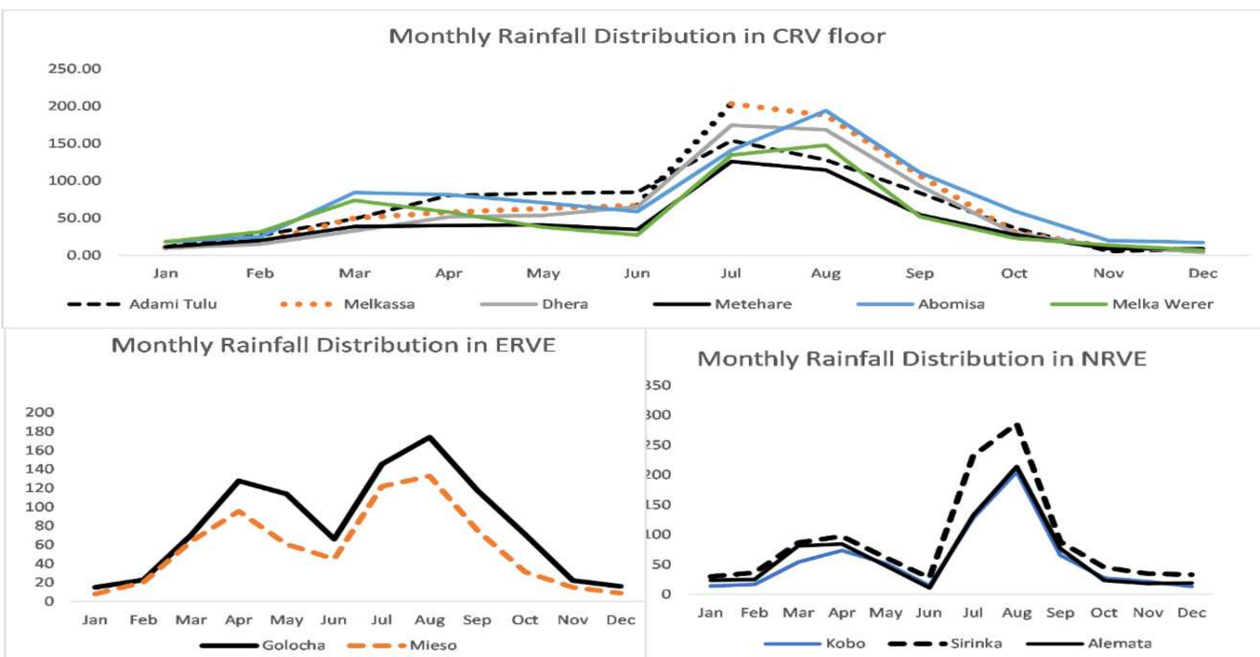
where Pd is the probability of the days being dry and Fd is the number of dry days, Pdd is the probability of dry days followed by another dry day, and Fdd is the number of dry days followed by another dry day during the growing season.

3. RESULTS AND DISCUSSIONS

3.1. Distribution and variability of monthly, seasonal, and annual rainfall

3.1.1. Monthly distribution and variability of rainfall

The investigated regions exhibit diverse long-term mean monthly precipitation patterns and fluctuations across the studied sites, with a minimum value of 4 mm observed at Dhera (CRV floor) during December, and a maximum of 286 mm recorded in Sirinka (Northern Rift Valley escapement) during the wettest month of August, spanning the years 1981 to 2021 (as depicted in Figure 2). Consequently, a notable degree of monthly rainfall variability was observed in the regions of interest, as depicted in Figure 2. The months of August and July have been observed to exhibit the greatest long-term mean monthly precipitation levels during the primary growing season. Subsequently, the amount of precipitation recorded during September in the entirety of the examined regions was determined. The occurrence of augmented precipitation in the northernmost regions (Alemeyehu and Woldeamlak, 2016) and eastern areas (Teshome et al., 2021) of Ethiopia throughout the months of August, June, and September has been ascertained. The data presented in Figure 3 illustrates that the mean monthly precipitation was at its minimum during the months of November, December, January, and February. The months of November, December, January, and February were observed to exhibit the lowest levels of precipitation across all analyzed sites as depicted in Figure 3. The examined locations displayed the highest level of monthly rainfall variability, as evidenced by Figure 2. The aforementioned statement suggests that there exists a considerable variation in both the pattern and amount of rainfall, as well as its distribution throughout the months. The short precipitation season offers an opportune time for land preparation or the sowing of expeditiously maturing crops like mung beans. Conversely, the principal precipitation season presents an opportunity for the cultivation of superior sorghum varieties that attain maturity in a span of three to four months. The cultivation of crops, particularly sorghum var., is highly influenced by significant fluctuations in precipitation and unstable weather patterns during the wet season. This necessitates the employment of supplementary irrigation techniques to ensure optimal crop growth and yield. Additionally, crops with limited maturation periods are preferred to mitigate potential losses due to adverse weather conditions. These particular recommendations, amongst others, are proposed.



Figure,2 Monthly rainfall distribution and variability in CRV floor, Northern (NRVE), and Eastern (ERVE) rift valley escapements.

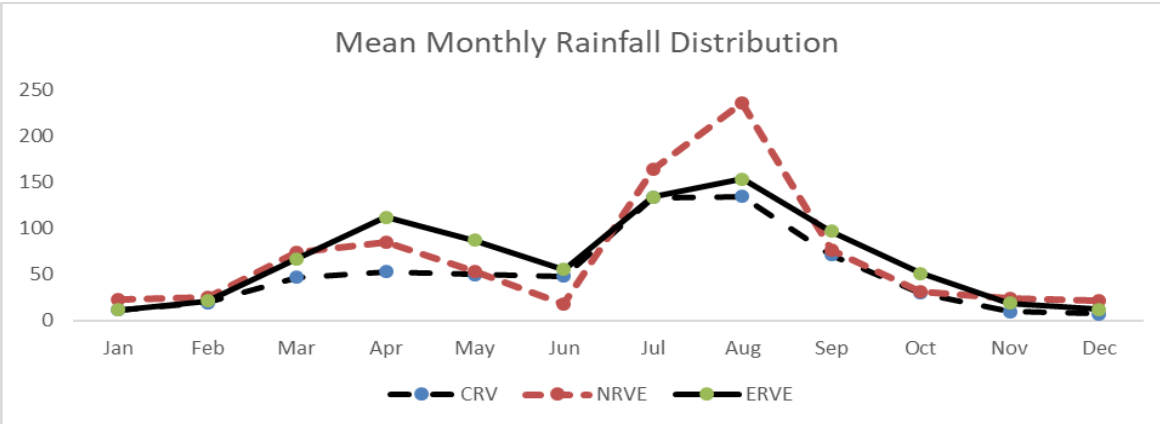


Figure 3; the total mean monthly rainfall distribution and variability in CRV floor, Eastern (ERVE), and Northern (NRVE) Rift Valley escapements.

The studied areas exhibited substantial fluctuations in the monthly rainfall's proportional contribution to the annual aggregate rainfall (Figure 4). The months of August and July were found to be the dominant contributors to the overall annual precipitation, while September emerged as the second largest contributor across all study sites, as shown in Figure 4. The tri-monthly period characterizes the most precipitous months, which are of paramount importance for the cultivation of crops at large, with a particular emphasis on crops or cultivars that mature early on. During the study period, the months of December, January, November, and February exhibited the lowest levels of rainfall across the examined regions. These months, known for their comparatively arid conditions, accounted for a minimally contributive portion of the annual rainfall within the area (see Figure 3). Nonetheless, the rainfall levels recorded during the months of March, April, and May exhibited significantly diminished contributions in terms of the aggregate annual rainfall amounts across all analyzed regions.

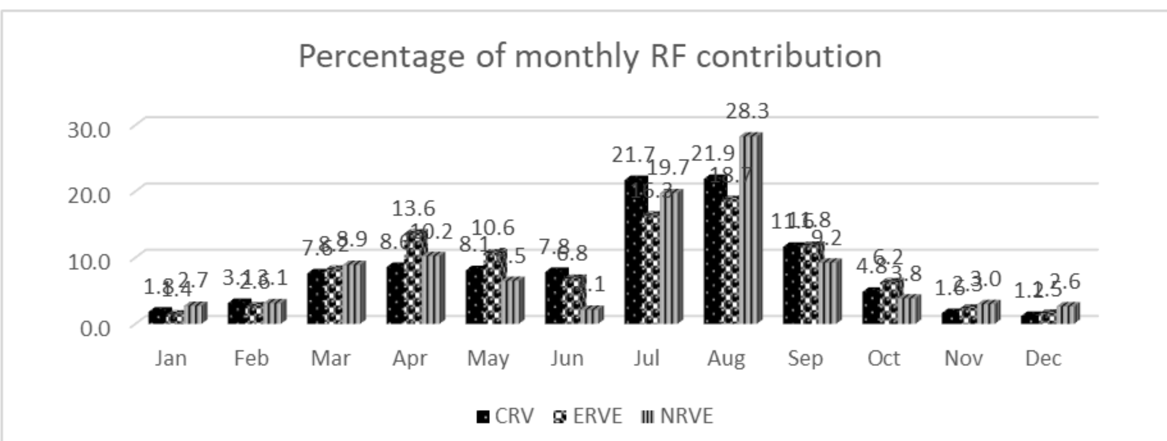


Figure 4. The percentage of monthly rainfall contribution to the annual rainfall in CRV floor Eastern (ERVE), and Northern (NRVE) Rift Valley escapements

3.1.2. **Seasonal and annual rainfall distribution and variability**

The present study has established that the percentage of overall rainfall recorded within the limited rainy season from March to May varied between 19.4% and 33.2% of the total annual rainfall levels in the specified study sites (refer to Table 2). The rainfall acquired during the main growth period, encompassing the months of June to September, reveals that it accounted for a substantial proportion ranging from 52.3% to 70.8% of the entire annual rainfall in the areas under study. This finding is indicative of the significance of rainfall patterns during the main growing season for agricultural production and ecological stability in the examined regions. The present study's results are supported by previous research conducted by NAP (2019) and the World Bank (2021), which demonstrated that the primary rainy season is responsible for a significant proportion of the yearly rainfall in Ethiopia. This abundance of rainfall facilitates the successful cultivation of 85-95% of the nation's food crops and contributes to approximately half of the country's overall productivity (Degefu, 1987; Korecha and Barnston, 2007).

The short rainy season spanning from March to May and the second rainfall season, commonly referred to as 'Arefasa or belg,' are characterized by a cumulative monthly rainfall amount of 100-200mm. Following this, a less significant wet season referred to as 'Bona' or 'Bega' rainy season occurs between the months of October and December. Of great significance is the primary rainy season, which extends from mid-June to mid-September (JJAS) and impacts the majority of Ethiopia. In the wettest zones, monthly precipitation can exceed 350mm (Seleshi and Zanke, 2004; Korecha, 2014; Irish AID, 2018). According to reports Nicholson, (2017), the majority of East Africa undergoes two rainy seasons, namely, the short (March to May) and main (June to September) durations annually.

In the studied localities, the rainfall levels observed during the short rainy season (March to May) varied between 116.6 mm at Matahara, situated on the floor of the CRV, and 296.8 mm at Gololcha, located on the Eastern RV escapement, as presented in Table 2. The region exhibiting the greatest degree of rainfall variability during the short rainy season (March to May) was found to be the northern Rift Valley Escarpment's (Kobbo) area. Throughout the main cultivation period, namely, from June up to September, the amount of rainfall varied considerably, spanning from 315.05 mm (Matahra within the Central Rift Valley's floor) to 618.8 mm (Sirinka in the northern Rift Valley's escapement) (Table 2). During the short period of rainfall, a majority of the locations within the analyzed regions, specifically over 91%, received less than 250 mm of rainfall per season. Additionally, based on the coefficient of variability (CV%), it was observed that there was a significant variability in rainfall among all stations, with the maximum CV being greater than 30%. During the main period of growth, a percentage of 45 of the examined regions received an excess of 450mm of rainfall. During the short rainy season, a substantial amount of variability in precipitation among all stations was observed, with a coefficient of variation (CV) greater than 30%. Conversely, during the primary growth period, the majority of stations (i.e., 63.6%) exhibited a moderate degree of variation, which corresponded to rainfall amounts ranging from 20% to 30%(Table 2). The findings of the analysis indicated the presence of a weak bimodal pattern of rainfall in the regions under study.

The study focused on the annual rainfall distribution observed within the examined regions. The results indicate the average total annual rainfall in the CRV floor, specifically in the Matahara area, was estimated at 505.7mm, while the northern RV escapement region, particularly Sirinka, received an average of 1007mm between the years 1981 and 2021. According to Table 2, it can be observed that except for Sirinka and Gololcha, a major proportion of the assessed locations exhibited annual rainfall levels that were below 800 mm. The regions under investigation manifest annual rainfall variability of moderate degree (with a coefficient of variation of less than 30%) as determined by the coefficient of variability (%CV). The present study examines the annual distribution of rainfall in the investigated areas and identifies a weak bi-modal rainfall pattern that is divided into two distinct seasons, namely, the short and main rainy seasons. Furthermore, in the studied areas, there was a notable degree of inter-seasonal fluctuation regarding rainfall, with a coefficient of variation (CV) exceeding 30% during the short rainy season and experiencing moderate variability, ranging from 20-30% CV, during the main season. On average, the magnitude of the contribution of the short rainy season referred to as "MAM" to the total annual precipitation was notably lower, ranging between 39 to 61.3%, in comparison to the main rainy season. Furthermore, the studied areas exhibited a higher degree of rainfall variability during the short rainy period as opposed to the principal rainy season.

The results of the present analysis reveal a substantial difference (exceeding 30%) in precipitation levels across the examined regions during the two distinct seasons. The fluctuations in precipitation patterns significantly affect the crop yield and efficiency of agricultural production within the study sites. It is imperative for the region to implement adaptive strategies that entail the cultivation of early-maturing sorghum and other crop varietals. Furthermore, moisture conservation techniques and rainwater harvesting practices must be accorded priority.

Table 2. Seasonal and annual rainfall (mm), contribution (CT), CV %, and PCI for representative meteorological stations in the CRV floor, Northern and Eastern escapements of the Rift Valley of Ethiopia.

Regions	Station	Short Rainy season (mm)			Main Rainy season (mm)			Annual (mm)		PCI %
		Mean	CT %	CV%	mean	CT %	CV%	mean	CV %	
CRV floor	Adami Tullu	202.07	28.3	41.7	428.05	59.9	27.7	713.5	20.2	16.4
	Melkassa	169.6	21.3	44.4	546.64	68.9	25.6	793.2	21.7	18.5
	Dheera	130.8	**19.4**	53.3	476.8	**70.8**	42.9	673.2	31.7	19.4
	Metehara	116.6	23	52.4	315.05	62.2	29.7	505.7	24.3	19.1
	Abomisa	231.02	27.3	32.5	481.02	56.8	26.1	846.	20.5	15.6
	MalkaWarer	161.2	27	50.8	343.9	58	33.5	593	23.6	18.2
Eastern RV escapement	Gololcha	296.8	32.4	31.5	479	**52.3**	20	916	14.5	14.4
	Mieso	219.5	**33.2**	51.2	360.8	54.6	33	660.5	27.2	17.2
Northern RV escapements	Kobo	171	25.9	88	398.7	60.6	28.8	657.7	37.7	19.9
	Sirinka	233.95	23	50.3	608.4	60	26.5	1007	21.5	37.0
	Alamata	203.3	28	46.9	413.1	57	45	719.5	26.7	21.1

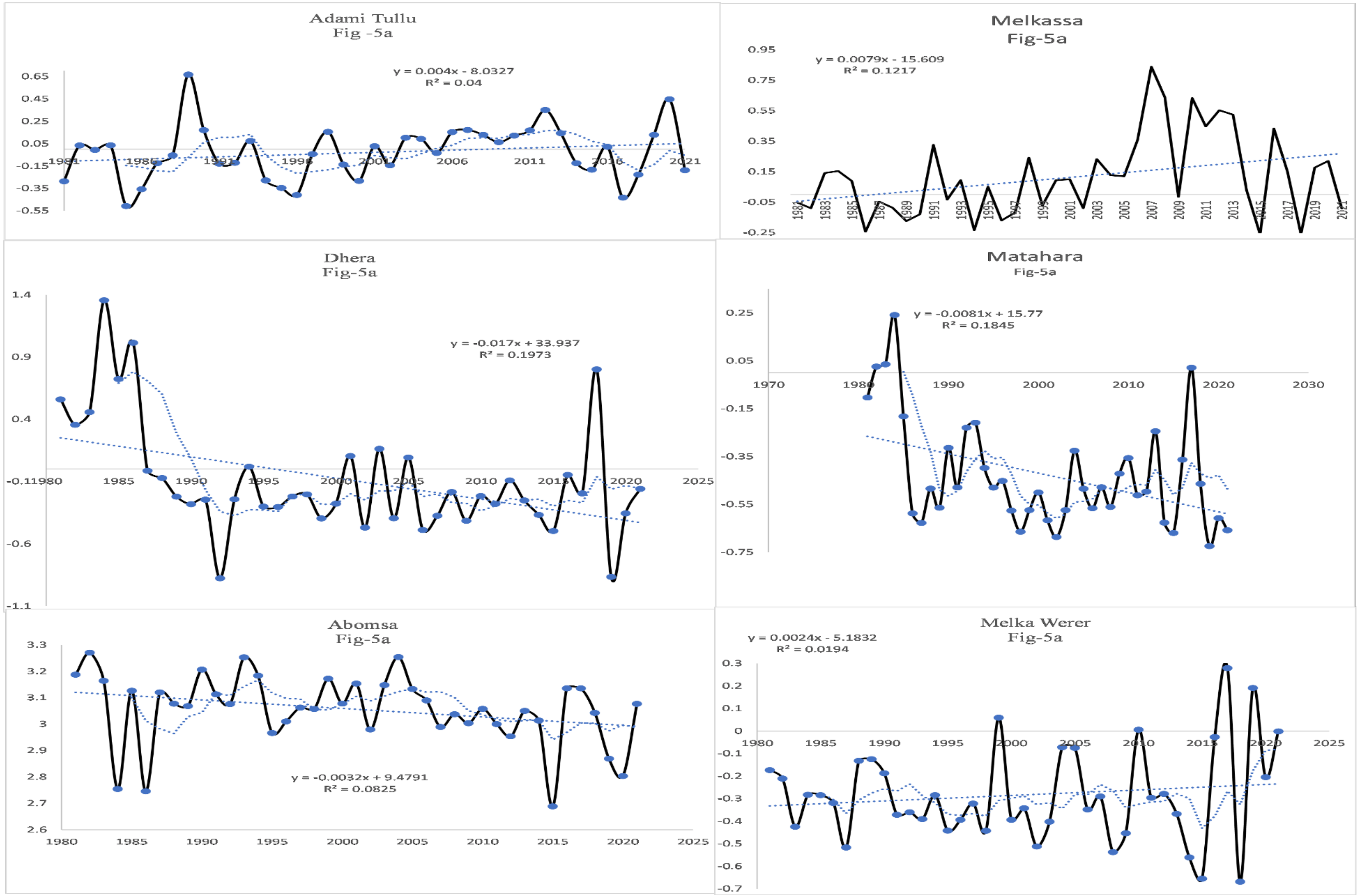
The main *season* spans from June to September, while the short rainy season spans from March to May; Where, CT=contribution, CV (%) =coefficient of variation, and PCI = Precipitation Concentration Index. RV=Rift valley

Between 1981 to 2021, the annual values of the Precipitation Concentration Index (PCI) for the locales under study exhibited a wide spectrum, with recorded values surpassing 37.03 at Sirinka, the northern RV escapement, and minimally exceeding 14.1% at Gololcha in the eastern RV escapement. According to Table 2, as per documentation. Moreover, the mean values of the PCI in the examined regions exhibited variations during the year. The results presented in Table 2 indicate that the PCI value exceeded 11% for all stations in the analyzed zones. This observation suggests a noteworthy precipitation concentration during specific seasons in the investigated areas. Several research studies, namely, those conducted by Bekele et al. (2016) and Adem et al. (2019), have demonstrated that the Rift Valley region, characterized by a semi-arid climate, exhibits a notably high magnitude of annual precipitation, ranging from high to extremely high annual rainfall concentrations.

2.1.1. **Annual and Seasonal rainfall standardize anomalies**

The standardized anomaly index (SAI) values for the studied regions were computed for each year from 1981 to 2021, marking different time intervals, as shown in Figure 5. In this study, SAI was utilized to demonstrate the interannual change in the area, time scale, and drought intensity, as well as its frequency. The results presented in Figure 5 demonstrate noteworthy discrepancies in the frequency of rainy and dry years among distinct locations, revealing a significant level of variability. The annual fluctuations in the CRV floor's dryness frequency and tendency span from a complete absence of dry spells in Abomisa to a comparatively drier situation in Metehare, as shown in Figure 5a. It is frequently observed in the examined regions that a pattern of consecutive dry years ensues subsequent to a singular dry year, and conversely, a comparable trend prevails.

In the regions under study, droughts would periodically manifest with a frequency ranging from every three to ten years. For example, the eastern RV escapement experienced a drought lasting four years, while the CRV floor at Adami Tullu was impacted by a prolonged drought lasting six years. Similarly, the CRV floor areas of Malka, Were and Matahara also underwent persistent drought conditions, as depicted in Figure 5. The present study examined a significant association between variables (Figs 5a and 5b), focusing particularly on the temporal span from 1981 to 1988 and 2003 to 2013. Except for Abomsa, all stations encountered varying degrees of drought conditions, ranging from mild to severe. The CRV floor has been demonstrated to be particularly susceptible to drought during the preceding four decades, as ishown in Figures 5a and b, with Matahara and Malka Werer being identified as particularly arid regions. Within the studied region, annual precipitation frequently exhibited a cyclical pattern characterized by periods of abundant and scarce rainfall. Over a period of observation, approximately 35% of the years were marked by the occurrence of negative anomalies, as illustrated in Figure 5. SAI was useful in displaying the intensity and frequency of drought at different time scales as well as defining the aspects of drought, according to Hadgu et al. (2013), Bekele et al. (2016), Girma et al. (2018), and Teshome et al. (2021).


Adami Tullu
Fig -5a
y = 0.004x - 8.0327
R² = 0.04
0.65
0.45
0.25
0.05
-0.15
-0.35
-0.55
Melkassa
Fig-5a
y = 0.0079x - 15.609
R² = 0.1217
0.95
0.75
0.55
0.35
0.15
-0.05
-0.25
Dhera
Fig-5a
y = -0.017x + 33.937
R² = 0.1973
1.4
0.9
0.4
-0.1
-0.6
-1.1
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Matahara
Fig-5a
y = -0.0081x + 15.77
R² = 0.1845
0.25
0.05
-0.15
-0.35
-0.55
-0.75
1970
1980
1990
2000
2010
2020
2030
Abomsa
Fig-5a
y = -0.0032x + 9.4791
R² = 0.0825
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Melka Werer
Fig-5a
y = 0.0024x - 5.1832
R² = 0.0194
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

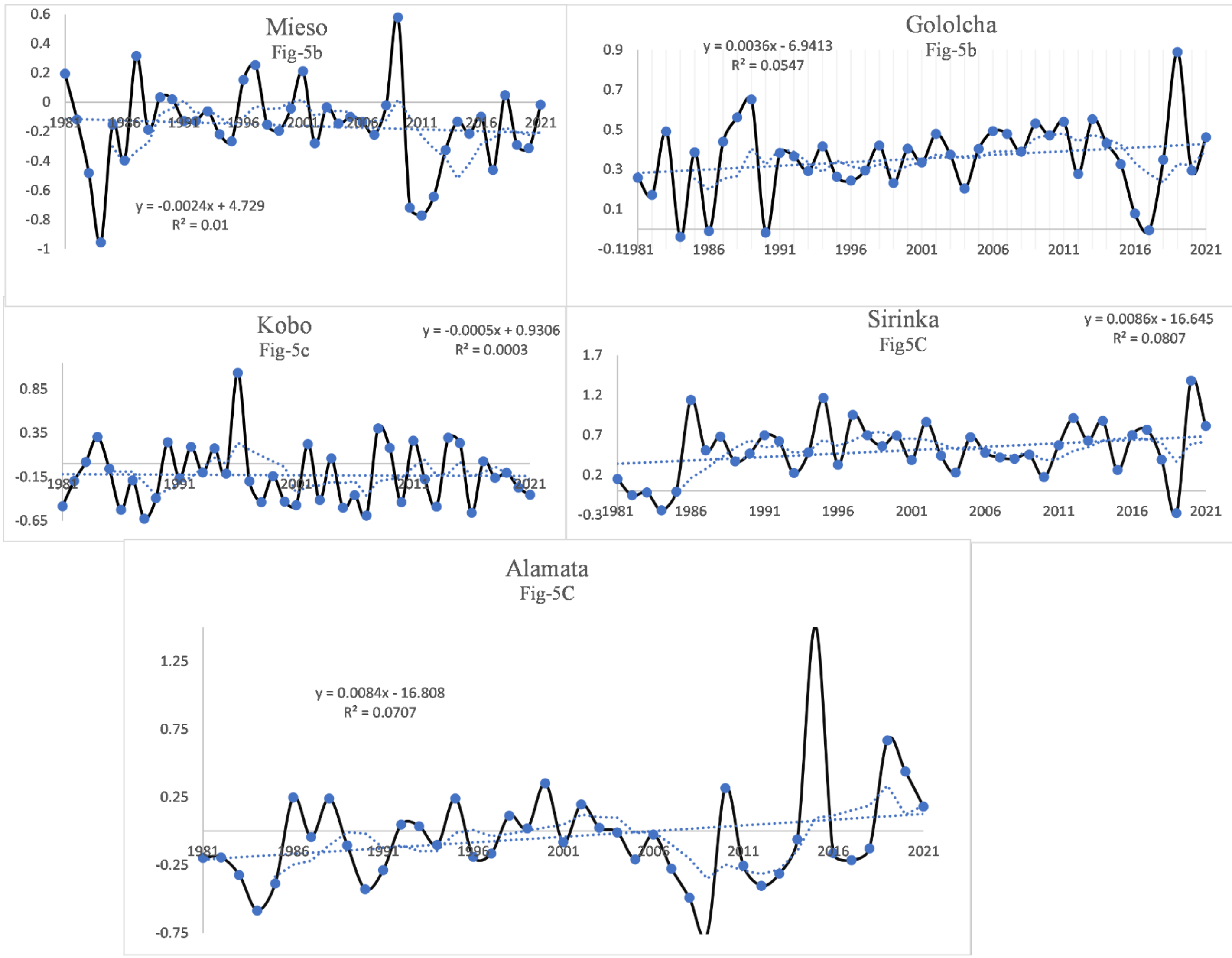
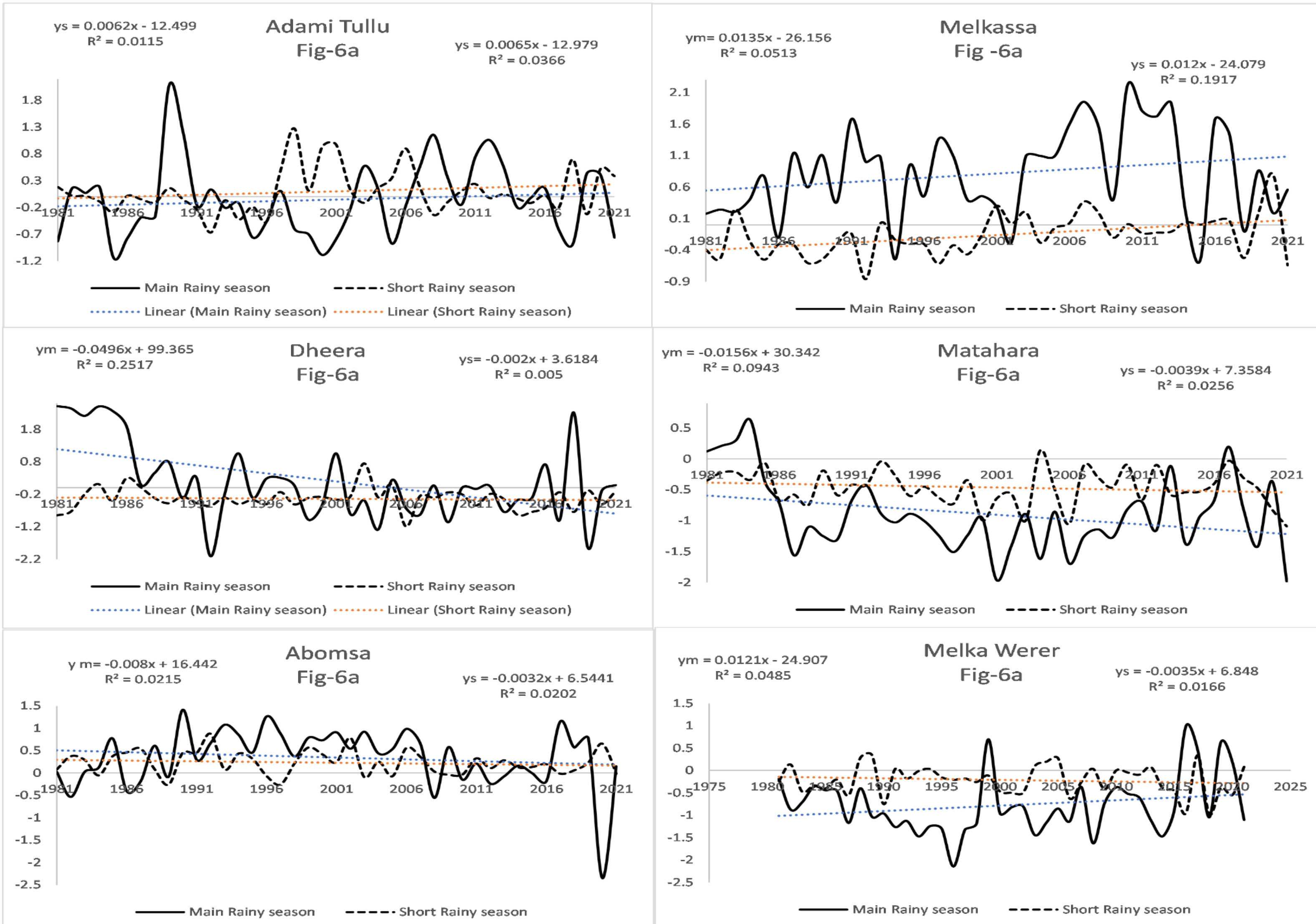


Fig 5.Annual Standardized for annual rainfall in CRV foot (Fig-a), eastern (Fig-b), and northern (Fig-c) RV escapements of Ethiopia over 1981-2021. The dotted line represents the 5-year moving average

The time series analysis of seasonal rainfall indicated, the short (March-May) and main (June-September) rainy seasons did not exhibit similar patterns among the examined regions over the years (Figure 6). Nonetheless, it should be highlighted that prolonged periods of drought occurred during the main as well as short rainy seasons, as shown in Figure 6a, within the vicinities of Matahara and Melka Were, particularly on the CRV floor. Throughout the short duration of the rainy season, intermittent dry periods were observed in the regions of Dhera and Melkassa, suggesting a place that exhibited a compromised bi-modal rainfall pattern spanning over the preceding forty-year. The graphical presented in Figure 6 demonstrates an assessment of climate conditions, characterized as normal, wet, and dry, respectively, denoting an overall average, above-average, and below-average year. This measurement is conducted using the Standardized Anomaly Index (SAI). The present study reports on the variation of Standardized Anomaly Index (SAI) values during the main and short rainy seasons. The SAI values recorded during the major rainy season ranged from 2.18 (very dry conditions) to 3 (extremely wet conditions). In contrast, during the short rainy season, the recorded SAI values ranged from 1.14 (moderately dry conditions) to 1.67 (extremely wet conditions). Over the last four decades, both seasons have exhibited periods of aridity and high rainfall, as depicted in Figure 6. Throughout the duration of the 40-year study, the preponderance of the research locations experienced prolonged spells of aridity lasting between 20 and 36 years, intense droughts persisting for a duration of 1 to 5 years, and exceptionally wet years occurring for a timeframe of 1 to 7 years. Notwithstanding the presence of a short wet spell, the observation units of the research areas have recurrently encountered conventional aridity patterns during the preceding four decades (as depicted in Figure 6). Based on the study's results, the agricultural yield of the examined areas and the state of food security have been profoundly impacted due to the rise of drought frequency during both farming seasons.


Adami Tullu
Fig-6a
ys = 0.0062x - 12.499
R² = 0.0115
ys = 0.0065x - 12.979
R² = 0.0366
Main Rainy season
Short Rainy season
Linear (Main Rainy season)
Linear (Short Rainy season)
Melkassa
Fig -6a
ym= 0.0135x - 26.156
R² = 0.0513
ys = 0.012x - 24.079
R² = 0.1917
Main Rainy season
Short Rainy season
Dheera
Fig-6a
ym = -0.0496x + 99.365
R² = 0.2517
ys= -0.002x + 3.6184
R² = 0.005
Main Rainy season
Short Rainy season
Linear (Main Rainy season)
Linear (Short Rainy season)
Matahara
Fig-6a
ym = -0.0156x + 30.342
R² = 0.0943
ys = -0.0039x + 7.3584
R² = 0.0256
Main Rainy season
Short Rainy season
Abomsa
Fig-6a
y m= -0.008x + 16.442
R² = 0.0215
ys = -0.0032x + 6.5441
R² = 0.0202
Main Rainy season
Short Rainy season
Melka Werer
Fig-6a
ym = 0.0121x - 24.907
R² = 0.0485
ys = -0.0035x + 6.848
R² = 0.0166
Main Rainy season
Short Rainy season

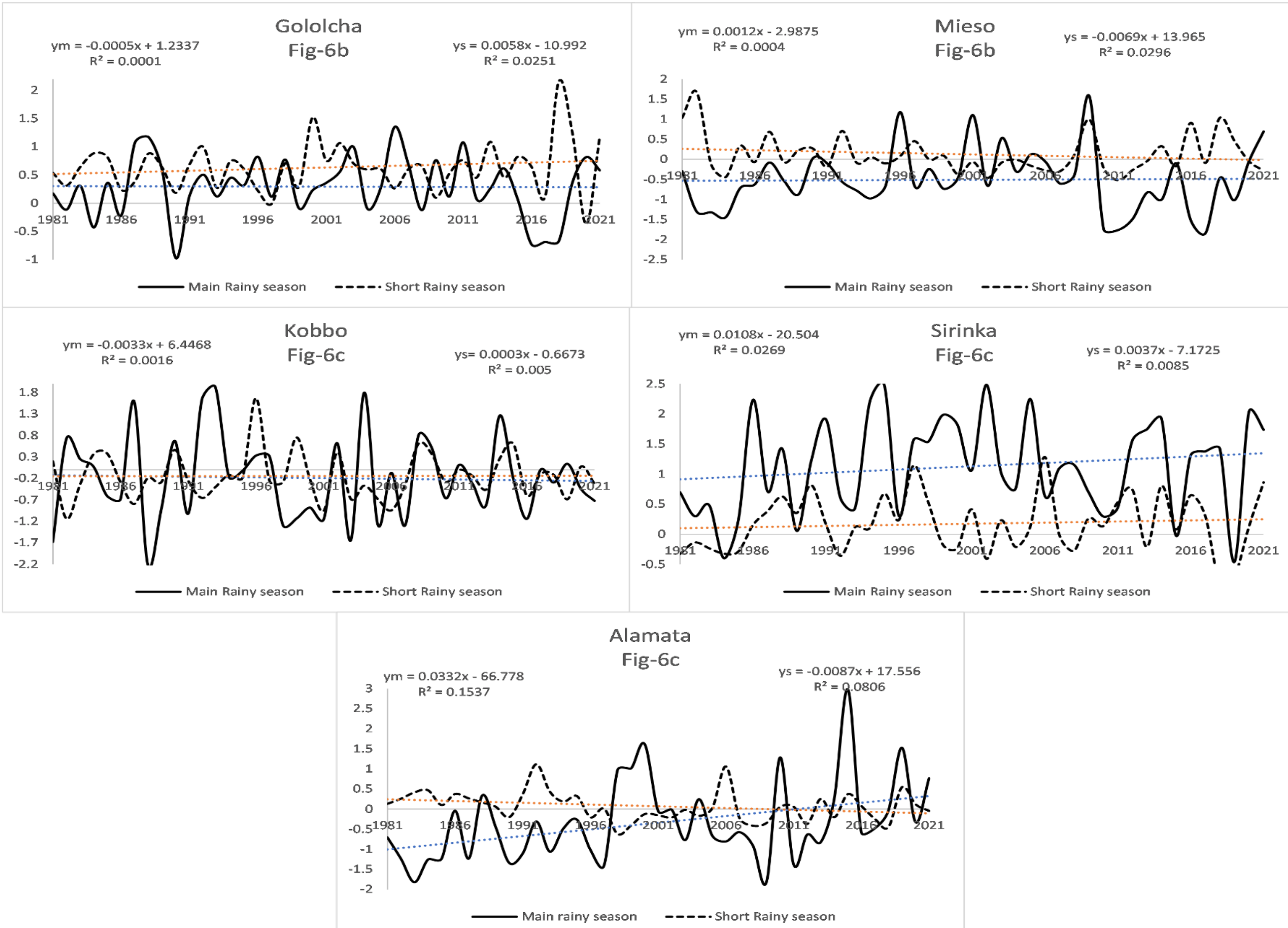


Fig 6 Standardized anomaly index (SAI) for seasonal rainfall in CRV floor (Fig-6a), eastern (Fig-6b), and northern (Fig-6c) RV escapements of Ethiopia over the period 1981-2021

3.2. Monthly, Seasonal, and Annual Rainfall Trend

3.2.1. Monthly rainfall trend

The findings of Mann-Kendall and Sen's statistical analyses for trend estimation indicate that the levels of monthly rainfall exhibit diverse patterns across distinct periods of time and locations, whereby certain trajectories exhibit an upward tendency, while others display a downward trend. The trends of ascent and descent were devoid of statistical significance ($P < 0.05$) in all analyzed locales except for Dhera, Abomsa, and Matahara (central rift valley floor) (Table 3). The findings for the months of March and April indicated a decline trend in five, two, and three research sites located in the Central Rift Valley (CRV) floor, Eastern, and Northern Rift Valley escarpments, respectively, as per the results obtained from the Mann-Kendall test. The relevant data is presented in Table 3. Sen's analysis indicated a pattern of declining rainfall in the investigation area during March and April, contrasted with an increase in the CRV floor (excluding Matahara) and the Eastern Rift Valley (Golocha) during May. This finding may highlight the variation in rainfall trend across the region of interest during the analyzed period. Over the past four decades, a decline in rainfall trend has been observed during the months of March and April in the measured areas, while an upward trend has been identified in May throughout most of the CRV floor regions. This result corroborated with Hadgu et al. (2013) and Adem et al. (2017) the total amount of rainfall in northern Ethiopia decreased from March to May, whereas increase in CRV.

During the period between June and September, it was observed that the majority of stations within the analyzed regions exhibited statistical non-significance ($P < 0.05$) in the upward trend of rainfall. Nevertheless, certain sites displayed a statistically significant trend of decreasing rainfall amounts across the region, as evidenced by the Mann-Kendall trend test (Table 3). June represents the start of the main rainy season and constitutes a contribution ranging from 2.1 to 7.8% of the total annual rainfall received in the area, as shown in Figure 4. During June, an upward trend statistical non-significance ($P < 0.05$), was observed. Furthermore, a rise in rainfall levels across all examined regions was observed, with a range of 0.43 to 1.78 mm per year in the CRV floor, 0.38 to 87 mm in the eastern escapements, and 0.14 to 0.22 mm per year in the northern escapements. According to Figure 4, the period of September was found to constitute 9.2 to 11.8% of the accumulated yearly rainfall in the examined areas, and it marked the end of the major rainy season. The rainfall trend recorded in September within various stations located on the floor of the CRV region, as well as the northern and eastern Rift Valley escarpments, failed to demonstrate a statistically noteworthy increase, apart from the Kobbo station located in the northern Rift Valley escarpment. The Kobbo station registered a considerable upward trend, as evidenced in Table 3, with a statistical significance level of $P < 0.001$. In the CRV floor regions, namely, Dhera, Abomsa, and Melka Were, the rainfall trend in September exhibited a non-significant decreasing pattern. However, an exceptional noteworthy decline was observed in Dhera, which demonstrated a significant ($P > 0.01$) downward trend. According to Sen's slope estimation, the rainfall trends during September demonstrated an increase across the eastern, northern, and CRV floor regions of the studied regions, progressing from 0.14 to 0.29, 0.05 to 0.71, and 0.02 to 0.81 mm per annum, respectively. Conversely, the CRV floor region of Melka, Werer, Abomsa, and Dhera displayed a decrease in rainfall trend ranging from 0.18 to 0.54 mm per annum, as indicated by the data recorded in Table 3. On the other hand, despite the variability and trend seen along the studied stations, regarding the magnitude and direction of rainfall, most stations displayed downward and upward trends during September. This finding suggests a reduction in the duration of the growing season and a concomitant increase in the frequency of terminal drought.

Table 3; Trends of monthly (March-September) rainfall totals in CRV floor, Eastern and northern RV escapements, Ethiopia, for the year 1981-2021

Regions	Study areas	Month													
		March		April		May		June		July		August		September	
		Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q
Central Rift Valley floor	Adami Tullu	0.011	0.021	-0.15	-0.075	0.28	0.14	2.73*	1.17	1,81*	1.44	-0.39	-0.27	0.39	0.14
	Melkassa	-0.57	-0.29	0.55	0.25	0.44	0.23	1.16	0.55	-0.48	-0.45	-1.22	-0.87	0.53	0.29
	Dheera	-2.2*	-0.62	-0.86	-0.36	0.75	0.38	1.09	0.71	-0.55	-0.63	-0.99	-1.19	-1.9*	-1.13
	Metehare	-2.4*	-0.82	-1.94*	-0.57	0.17	0.14	-1.86*	-0.71	-1.44	-1.13	-0.99	-0.51	0.51	0.22
	Abomisa	-2.3*	-1.78	-0.79	-0.32	0.64	0.43	1.02	0.43	0.31	0.29	0.87	0.49	-0.54	-0.5
	Malka Werer	-1.4	-0.57	-1.33	-0.47	-1.38	-0.36	-1.34	-0.22	0.079	0.031	0.30	0.39	-0.64	-0.18
ERVE	Gololcha	-0.24	-0.15	0.056	0.056	0.08	0.09	0.93	0.38	-0.64	-0.54	1.04	0.71	0.95	0.71
	Mieso	-1.56	-0.97	-0.51	-0.42	-0.06	-0.06	2.33*	0.83	1.43	0.82	1.11	0.64	0.08	0.05
NRVE	Kobo	-0.72	-0.31	-1.58	-0.59	0.157	0.07	1.236	0.15	0.606	0.39	-0.69	-0.59	1.9*	0.81
	Sirika	-0.17	-0.11	-1.45	-0.59	-1.55	-0.57	0.87	0.22	1.38	2.24	1.72*	1.78	-1.38	-0.5
	Alamata	-1.2	-0.59	-0.46	-0.32	-1.34	-0.84	1.56	0.14	2.7**	1.86	1.88	1.64	0.06	0.02

ZMK =Mann–Kendall trend=Sen's slope, ERVE= Eastern Rift Valley escarpment, and NRVE=Northern Rift Valley escapement.

3.2.2. Seasonal and annual rainfall trends.

According to the Mann-Kendall trend estimation, the majority of stations located in the study regions demonstrated a non-significant ($P \leq 0.05$) downward trend. However, within the past four decades, two stations, specifically Melkassa in the CRV floor and Gololcha located in the Eastern Rift Valley escarpment (ERVE), exhibited an upward trend during the short rainy season. Three stations exhibited notable negative trends during the short rainy season, specifically Matahara located on the CRV floor, Kobbo, and Sirinka situated on the Northern Rift Valley Escarpment(NRVE), as indicated in Table 4. Abegaz and Abera (2020) have reported comparable results in the northern region of Ethiopia. Simultaneously, the Sen.'s slope estimator revealed an observable decline in rainfall tren during the short rainy season at all observed locations, ranging from 0.219 to 1.83, 1.74, and 1.56 to 2.76 mm annually in the CRV floor, Eastern, and Northern RV encampments, correspondingly. Despite this fact, there was an increase in rainfall at Melkassa, situated on the CRV floor, and at Gololcha, located on the eastern RV escarpment, with an average increase of 0.053 and 0.87mm per year during the short rainy season, respectively.

In Ethiopia, the main cultivation period for food crops falls within the main rainy season (Degefu, 1987; Korecha and Barnston, 2007), which comprises between 52.3 to 70.8% of the overall rainfall for the specific regions (Table 2). During the current season, it was observed that most stations located in the designated regions displayed an increase in rainfall trend. However, there were only two stations situated in the NRVE that exhibited a significant difference ($P \leq 0.05$) in comparison to the other stations (Table 4). Furthermore, the results of the Sen's slope estimator analysis indicate that rainfall during the main season exhibited an increase at Adami, Tullu, Melkassa, and Abomsa in the CRV floor, with values ranging from 0.19 to 2.08 mm per annum. On the other hand, the ERVE and NRVE depicted a positive trend with respect to the main season rainfall across a notable proportion of the examined stations, with values ranging from1.21 to 5.12 mm per annum. The present study reveals that there was a decline in the annual rainfall rates ranging from 0.49 to 2.25 mm in the CRV floor region as observed in the monitoring locations of Dhera, Matahara, and Melka Werer.

The Mann-Kendall trend estimation analysis of the yearly rainfall indicated a decreasing pattern in five stations situated within the region, namely, Dhera, Matahara, Abomsa, Melka, Werer (CRV floor), and Kobbo (Northern RV escapement). The present study reports an increase in trend of the studied parameters in five stations situated in distinct regions, namely, Adami Tullu and Melkassa (CRV floor), Gololcha (ERVE), Sirinka, and Alamata (NRVE). Among these stations, Adami, Tullu, and Matahara exhibited statistically significant differences ($P \leq 0.05$) in their data results. According to the Sens slope estimator, there was a notable increase in rainfall from 0.042 to 3.88 min per year within the regions under analysis. However, there was a decline observed in the range of 1.29 to 3.71 mm per year in five stations, namely, Dhera, Matahara, Abomsa, Melka, Werer (CRV floor), and Kobbo (NRVE) as presented in Table 4.

The CRV floor as well as the ERVE and NRVE of Ethiopia have exhibited a trend of declining rainfall amounts and patterns during the short rainy season. Conversely, a downward trend in rainfall amounts and patterns during the main rainy season and the overall annual rainfall has been observed mainly in the CRV floor at the majority of the locations studied. In previous studies, it has been established by the works of both by Kassie et al. (2013) and

Getachew and Tesfaye (2015) the investigation that region under study experiences a shortage in rainfall and is susceptible to drought due to variations in seasonal rainfall. However, except for Kobo located in the NRVE, a noteworthy decline was apparent in the annual rainfall levels. In contrast, both the main rainy season and the cumulated annual amount distinctly manifested an improving trajectory in both the ERVE and NRVE . The rationale for this phenomenon can be attributed to the rainfall accumulated during the extended monsoon period, as a result of the convergence of the pressure system of low magnitude and the intertropical merging zone (Tabari et al., 2015). It is plausible that this occurrence has been influenced by the on-going climate variability. The decrement observed in the main rainy season and the overall rainfall levels on the floor of the Central Rift Valley hold undesirable ramifications for the cultivation of rain-fed crops (Kassa, 2015).

Table 4. Trends of annual and seasonal rainfall totals in CRV floor, Eastern and Northern RV escapement, Ethiopia, for the year 1981-2021

Regions	Study areas	Short rainy season		Main rainy season		Annual	
		Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q
CRV floor	Adami Tullu	-0.15	-0.219	1.45	2.08	1.92*	3.88
	Melkassa	0.06	0.053	0.015	0.19	0.42	0.90
	Dheera	-0.46	-0.31	-0.71	-1.62	-0.75	-2.28
	Metehare	-2.37*	-1.83	-1.81*	-2.25	-2.62**	-3.71
	Abomisa	-1.54	-1.66	0.5	1.02	-1.41	-2.22
	Malka Werer	-2.5*	-1.97	-0.37	-0.49	-1.04	-2.55
Eastern RV escapement	Gololcha	0.55	0.87	0.99	1.21	0.034	0.19
	Mieso	-1.36	-1.74	1.72	2.03	0	0.042
Northern RV escapement	Kobo	-2.57*	-2.76	0.73	1.5	-0.48	-1.29
	Sirika	-1.69*	-1.56	1.72*	4.3	0.95	3.34
	Alamata	-1.72*	-2.35	2.53*	5.12	0.42	0.94

ZMK = Mann–Kendall trend test, Q=Sen's slope is the change (mm)/annual; ns is a non-significant trend at 0.05 and 0.1 and * indicates a significant trend at 0.1 significant level.

3.3. Growing Season Characteristics

3.3.1. Variability and trends at the start and end of the growing season's

The analyzed characters of the seasonal climate were determine the start and end of the main rainy cultivation period (June to September). Several investigations have previously demonstrated the significance of seasonal climate attributes, including the start, end, and duration of the growing season, as well as occurrences of dry spells. These attributes are vital in terms of effectively managing climate resources and crop cultivation practices within a specific geographical region. (Mugalavai et al., 2008; Solomon et al., 2015; Edao et al., 2018; Wagaye and Eshetu, 2021). The findings obtained from the examination of rainfall data at the eleven stations have revealed that there exists variation in the start and end of the dominant planting periods among the investigated regions (Table 5). The study revealed that the mean onset dates of the growing season varied substantially among the analyzed sites, ranging from Julian day number (DOY) 177 (i.e., June 25 at Dhera on the CRV floor) to 196 (July 6 at Mieso in the ERVE as presented in Table 5. The present study reports on the coefficient of variation (CV) for the start of the season (SOS) across different locations. Results indicate that the SOS CV ranged from 4.9% at Dhera to 16.6% at Adami Tullu on the CRV floor. The majority of the observed sites (72.7%) reported a start of the growing season on the first "dekad" of June (DOY 153), whereas the start of the growing season in the NRVE at Almata was observed to be the latest, occurring on the first dekad of July (DOY 196). The range of standard deviation (SD) values for the start of the season (SOS) observed across the examined sites exhibited a minimum of 12.7 and a maximum of 31.3 in the respective regions studied. This observation suggests that the stability of the SOS is compromised, as the SD recorded exceed the prescribed ranges proposed by Reddy (1990). This suggested, the patterns could be difficult to understand, and consequently, decisions on planting dates and related activities were made at high risk.

The present study reveals that the average end date of the growing season (EOS), in the various studied sities differs significantly. The mean end date of the growth season (EOS) in the studied regions ranges from the second dekad of October (DOY 285) at Abomsa in the CRV floor to the fourth dekad of September (DOY 274) at Malkassa in the CRV floor, with a coefficient of variance ranging from 0.1 to 4.1%. (Table 5). The earliest and latest ends of the season fall on the fourth dekad of September (DOY 274), at Malkassa on the CRV floor, and on the second dekad of November (DOY 320) at Abomsa on the CRV floor, respectively (Table 5). However, the start and end of the season did not show variations for the majority of stations in regions across the studied sites. The end of the growing season is determined by the amount of water that has been stored in the soil and will be available to the crop once the rains stop (Stern et al., 2011; Bekele et al., 2017; Edao et al., 2018).

In the analyzed regions and stations, the conclusion drawn from the data is that the end dates of the growing season were observed to be delayed by one and three days compared to the respective means at Melkassa and Adami Tullu. On the other hand, in Dhera and Abomsa, the growing season ended seven days earlier. The present study found that, in a comparable fashion to Gololcha, Mieso, and Kobbo, the growth period of Sirinka terminated prematurely by one day for each instance. Gololcha arrived six days prior to the anticipated date(Table 6). The other stations had changed at the end of the season by either staying the same or changing by just one day. However, most stations had small changes during the time when plants grow the most. The standard deviations showing the variances were between 0.15 (for Melka Werer) and 7.17 (Dhera) on the CRV floor" (Table 6). Farmers may choose to grow crops that take a long time or a short time to mature, depending on how the weather changes throughout the growing season. This helps them figure out when the best time is to harvest their crops.

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Table 5. Variability and Trend of LGP and NRD for eleven stations (1981-2021) in CRV floor, Easter, and Northern RV escapements of Ethiopia.

Features		Central Rift Valley floor						Eastern RV escapement		Northern RV escapement		
		Adami Tullu	Melkassa	Dheera	Metehare	Abomisa	Malka Werer	Gololcha	Mieso	Kobo	Sirinka	Alamata
SOS	mini	153	154	157	153	153	153	153	155	166	159	157
	max	299	219	201	233	233	233	221	233	230	215	214
	mean	185	180	177	190	184	190	184	196	192	186	181
	SD±	31.3	14.6	12.7	14.7	16.5	20.95	16.6	19.8	20.5	20.4	23.16
	CV	16.6	8.1	4.9	7.8	9	11.1	9.1	10.2	10.3	11.2	12.2
	Z_{MK}	-1.73*	-1.16	-2.39*	2.02**	-1.29	0.2	0.04	-2.3*	-0.57	-0.17	1.09
	Q	-1.39	-0.22	-0.31	0.33	-0.32	0.0	0.0	-0.64	-0.13	-0.11	0.18
EOS	Mini	279	275	275	275	275	275	275	275	275	275	275
	max	306	284	392	290	320	276	312	283	286	281	296
	mean	276	274	282	275	285	275	281	278	276	275	276
	SD	5.4	1.74	7.17	2.34	11.87	0.15	11.1	1.3	2.9	2.3	3.4
	CV	1.8	0.6	2.5	0.9	4.1	0.1	3.9	0.5	0.9	0.8	1.2
	Z_{MK}	0.0	0.0	-1.86*	0.0	-0.18	0.0	0.57	0.0	0.0	0.0	0.0
	Q	0.0	0.0	-0.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ZMK is Mann–Kendall trend test, Slope (Sen's slope) is the change (days/annual; **,* is statistically significant at 0.05 and 0.1 probability level; ns is the non-significant trend at 0.1; SD is standard deviation; CV is the coefficient of Variation

The present study has demonstrated that a significant modification of the start date of the growing season has occurred in the majority of stations within the analyzed regions over the past four decades, as determined by the Mann-Kendal trend and sens slope estimation results (Table 5). The start of the growing season showed decreasing trends ($P \leq 0.05$) in the majority of the analyzed stations (63.6%), and rising trends ($P \leq 0.05$) in four of the eleven studied stations.The end of the growing season indicated neither a lowering nor an increasing in magnitude in almost locations (Table 5).

3.3.2. Trend in the length of the growing period and number of rainy days

Upon the conclusion of the study, it was found that the length of the growing period (LGP) for sorghum cultivation during the main rainy season varies between 78 days in Kobo, situated in the Northern Rift Valley escapement, and 143 days in Golocha, located in the Eastern Rift Valley escapement. The findings derived from the analysis, as presented in Table 6, indicate that the coefficient of variation (CV) and standard deviation (SD) for the LGP in the examined regions ranged between 10.2% and 34.6%, and 10.7 and 31.3 for the Dhera and Adami Tullu regions in the CRV floor, respectively. In the examined locations, the main rainy season exhibited a range of length of growing period (LGP) varying from a minimum of 24 days in Adami Tullu situated in the CRV floor to a maximum of 200 days in Gololcha positioned in the eastern RV escapement (Table 6). The study revealed that the main rainy season in the areas under investigation exhibited significant interannual variability in both its onset and cessation. This condition served as a contributing factor to the high degree of interannual variability observed in the length of the growing period (LGP). Concurrently, the results obtained by Bekele et al. (2016) and Edao et al. (2018) have established that the timing of onset, whether early or delayed, and the corresponding timing of cessation, whether early or delayed, have significant impacts on the length of the growing season, causing seasonal variations.

The study revealed that the LGP at the majority of research sites exhibited a duration of three months or less over the past four decades, as presented in Table 6. The present findings have substantiated the need for an extended growth duration necessitated by sorghum cultivars, given their potential to reach maturity within a minimum of 90 days. Notably, the sufficiently long growing period has been observed to mitigate the likelihood of moisture stress in the study regions, thereby facilitating the cultivation of crops with minimal risk. The aforementioned statement suggests that the study areas are incapable of producing cultivars with a maturation cycle extending beyond 90 days under the circumstances of natural rain-fed conditions. The study revealed significant variability in the length of growing period (LGP) across the eleven stations examined. As a consequence of this observation, crop management practices should be exercised with marked prudence in order to ensure optimal yields. These practices may include, but not be limited to, timely planting decisions, careful selection of drought-tolerant or early maturing varieties, the adoption of effective tillage management techniques for the purposes of rainwater harvesting or soil moisture conservation, and the implementation of deficit irrigation as a supplementary practice to avert terminal stress and accomplish high productivity rates in long-cycle crop varieties.

Table 6. Variability and Trend of LGP and NRD for eleven stations (1981-2021) in CRV floor, Easter, and Northern RV escapements of Ethiopia.

Features		Central Valley Rift floor						Eastern RV escapement		Northern RV escapement		
		Adami Tullu	Melkassa	Dheera	Metehare	Abomisa	Melka Werer	Gololcha	Mieso	Kobo	Sirinka	Alamata
LGP	max	126	121	137	122	140	122	200	120	117	116	148
	min	24	56	82	42	52	42	87	40	45	60	61
	mean	90	95	104	86	98	80	143	80	78	88	85
	SD	31.3	14.78	10.7	14.8	18.7	20.95	25.356	19.8	21.5	19.1	23.25
	CV	34.6	15.6	10.2	17.3	19.2	24.5	17.8	24.8	23.9	16.5	27.7
	Z_{MK}	0.42	0.078	-0.31	-2.45*	0.18	-1.8*	1.47	1.3**	0.41	1.78	-.0.39
	Q	0.19	0.02	-0.13	-0.57	0.05	-0.4	0.31	0.61	0.12	0.4	-0.07
NRD	Max	106	110	119	115	122	120	122	113	107	108	98
	Min	38	62	14	33	61	45	72	52	32	43	45
	mean	67	83	101	75	103	88	110	89	83	90	75
	SD	14.788	10.04	20.8	18.8	12.57	19.6	8.9	14.65	15.2	14.38	11.3
	CV	22.1	12.1	20.1	25.1	12.2	22.2	8.1	16.5	18.3	16	15
	Z_{MK}	-1.41	-1.57	-1.64	-0.93	0.41	-3.2**	-0.55	0.67	-1.32	1.91*	1.46
	Q	-0,26	-0.21	-0.32	-0.3	0.05	-0.74	-0.032	0.14	-0.25	0.28	0.25

ZMK is Mann–Kendall trend test, Q is Sen's slope is the change (days/annual; **,* is statistically significant at0.05 and 0.1 probability level; ns is the non-significant trend at 0.1; SD is standard deviation; CV is coefficient of variation, LGP-length of the growing period, NRD-number of rainy days, Across the three geographic regions encompassing eleven stations, the average expected quantity of rainy days during the primary growing season varied between 67 days for Adami Tullu situated on the CRV planar surface to a maximum of 110 days for Gololcha located within the eastern RV escapement. This trend persisted over the duration of the period from 1981 to 2021. The results indicate that there was a range of variation in the frequency of rainy days during the main growing season, from a moderate percentage of 8.1% up to a high percentage of 25.1% (Table 6). Within the studied region, there existed varying levels of rainfall during the main period of plant cultivation, as evidenced by a maximum of 122 days and a minimum of 14 days with recorded rainfall. The present study revealed that there was a high degree of variability, with a coefficient of variation greater than 20%, in the number of rainy days at Adami Tullu, Dhera, Matahara, and Melka Were during the main growth period. This variability was observed to be consistent with interannual fluctuations and was notably higher than that recorded in the remaining stations. This finding shows that regions with high risk for effective crop cultivation exhibit significant variability concerning the number of days with rainfall.

The results of the Mann-Kendall trend estimation indicate a lack of statistical significance in the upward trend of LGP across the majority of the studied locations, accounting for 63.6% of sites during the past 40 years (Table 6). Conversely, some sites saw a downward trend in the number of rainy days, which was observed in about 36.4% of the study locations, as presented in Table 6. The findings from Table 6 indicate that in the studied regions, the LGP experienced an increase within the range of 0.02 to 0.61 per season, while the number of rainy days demonstrated a decrease ranging from 0.032 to 0.74 per season. However, it is noteworthy that in some regions, the lnght growth period (LGP) experienced a decreasing trend ranging from 0.07 to 0.74 per season in four of the eleven sites in the area under observation, while in the same four sites the frequency of rainy days exhibited an increasing trend ranging from 0.05 to 0.28 per season.

3.3.3. The probability of dry spell occurrence

Figure 7 displays the probability of extended periods of drought, ranging from 5 to 15 consecutive days without measurable rainfall (i.e., at least 0.85mm), during the primary growing season at the eleven studied stations throughout the investigated regions during four decades. The findings presented in Figure 7 (sp-5 and sp-10) demonstrate that the probability of a dry spell with a duration surpassing 5 and 10 days prior to the start of the main growth period (153 daily observation years (DOY)), is less than 40% in the CRV floor of Abomsa and ERVE of Gololcha, While being as elevated as 60% in the majority of other areas. The probability of a period of no rainfall lasting more than seven days is in excess of 80% at Abomsa and Gololcha prior to the main growth season, as outlined by the data . Moreover, the probability of a dry spell extending beyond two weeks (equivalent to a 15-day interval) is greater than 50% at more than half of the research stations investigated prior to the inception of June's onset (153 DOY), as depicted in Figure 7. The probability of a prolonged absence of rainfall, specifically lasting more than seven days, is noticeably substantial, surpassing 80% in the locales of Abomsa and Gololcha preceding the start of the main cultivation period, which transpires on the one hundred and fifty-third day of the year (DOY 153). However, the probability of encountering an absence of rainfall persisting for a period greater than two weeks, specifically lasting for fifteen days, is higher than 50% at more than half of the analyzed stations preceding the advent of June, which corresponds to DOY 153, as illustrated in Figure 7. Across all observed locations, except for Gololcha and Abomsa, the probability of a 5-day extension of a dry spell during the short rainy interval, MAM, surpassed 80%. Similarly, most analyzed sites evidenced a probability exceeding 60% of experiencing a 7-day increase in the duration of dry spells, except for Gololcha and Abomsa. This finding implies that Abomsa and Gololcha have the potential to generate crops that display resistance to drought with minimal exposure to risk amidst the short rainy season.

At the onset of the main agricultural cultivation period, the probability of experiencing a dry spell with a duration of one week or ten days is ascertained to fall below 35% (as depicted in Figure 7). However, at the study sites investigated, the probability of encountering a dry spell lasting for a period extending beyond two weeks is considerably minimized to below 20% (as indicated in Figure 7). The presented evidence indicates a diminished probability of cultivating crops that possess drought resistance within the aforementioned regions. In all studied locations, the probability of a prolonged period of dry weather, surpassing 5, 7, 10, or 15 consecutive days, is below 40% subsequent to the initial ten-day period in June. The probability of experiencing dry spells lasting 5, 7, and 10 days decreases to less than 20% during the start of the peak season (June, July, and August) and subsequently increases to 40% upon the occurrence of the 245^{th} day of the year in all stations, as illustrated in Figure 7. The regions under consideration exhibit weak bimodal rainfall patterns, resulting in prolonged dry spells exceeding 15 days, a factor that poses a significant challenge for growers intending to cultivate longer-maturing sorghum cultivars in the area. The present study indicates significant fluctuations in rainfall patterns during the developmental stages of crops, which have relevance in relation to the agronomic suitability of sorghum varieties with a condensed maturation phase. It is recommended that crops whose cycles extend into October be subjected to supplementary irrigation or moisture collection techniques. The above listed regions have undergone changes over the past four decades.

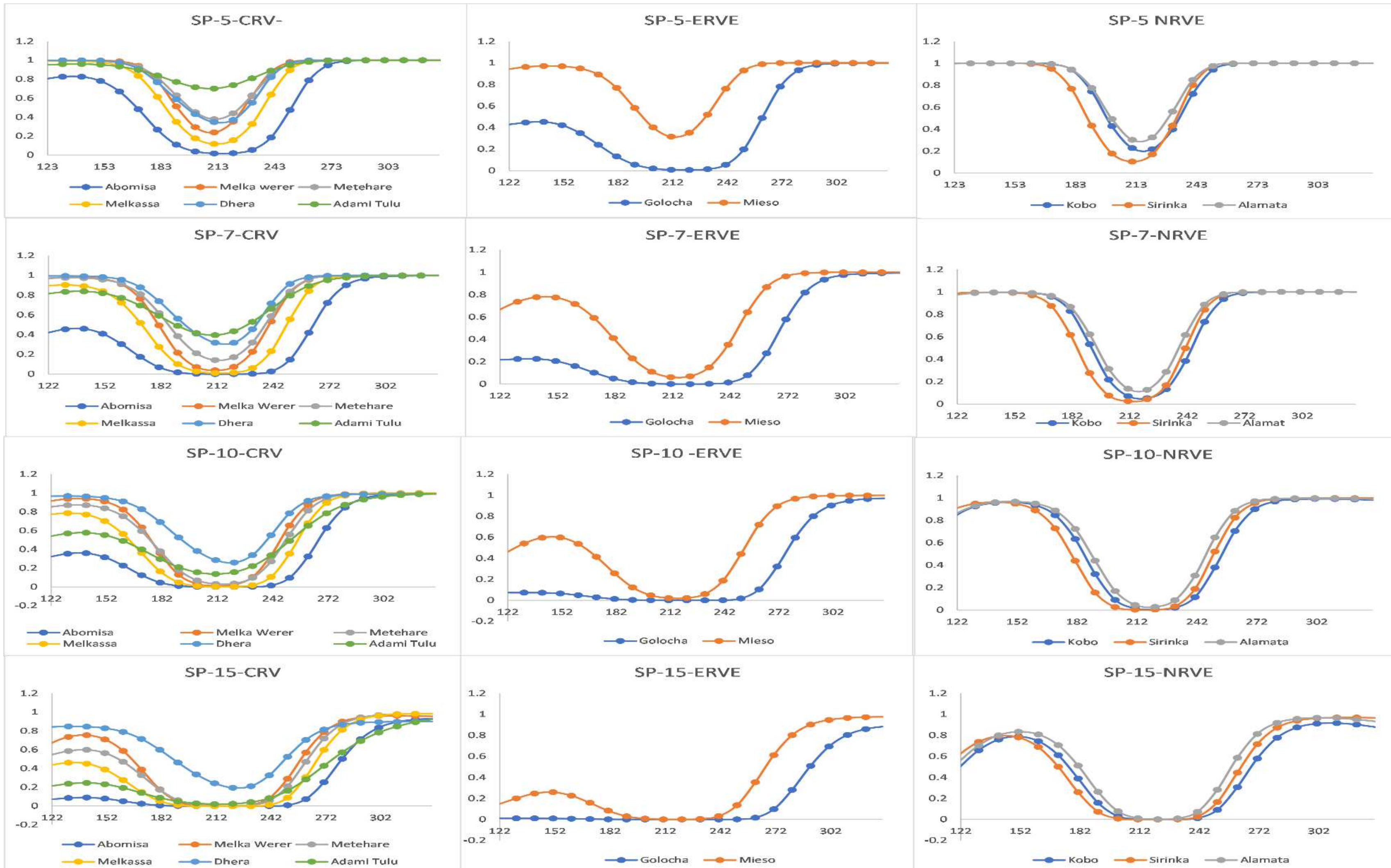

Figure 7; Probability of dry spells longer than 5, 7, 10, and 15 days in CRV (central rift valley), ERVE (eastern rift valley escapement), NRVE (northern rift valley escarpment) regions in the period of 1981-2021.

4. Conclusion

Over the past 40 years, the amount of rain that falls each month in Ethiopia's semi-arid rift valley has changed and varies greatly. This has led to noticeable changes in how much rainfall each month. August and July have the highest rainfall, followed by September. Next few months are crucial for crop growth due to low rainfall in March-May. These next few months are important for growing crops, especially those that don't take as long to grow. Rainfall was very low in the examined regions in December, January, November, and February.The rainy season (Mar-May) brought 19.4-33.2% of yearly rainfall, while the growth period (Jun-Sep) contributed 52.3-70.8%. Rainfall ranged from 116.6 to 296.8 mm during the short rainy season, with high variability in Northern Rift Valley Escarpment. Rainfall varied from 315.05 mm to 618.8 mm (Jun.-Sept.) and most areas received less than 250 mm per season. Rain varied greatly between stations with max CV >30%. 45% of the areas had excessive rain (450mm) during the growth period. Rainfall is highly variable (CV>30%) during the rainy season and moderately variable (20-30%) at 63.6% stations during the growth period. A weak bimodal pattern was observed.

The PCI mean values varied throughout the year, with all stations in the analyzed zones exceeding 11%. SAI values revealing variations in area, time scale, drought intensity, and frequency. Abomisa experiences no dry spells, whereas Metehare is comparatively drier. Droughts happen every 3-10 years in the studied areas. SAI measures the variation in rainy seasons: major rainy (2.18-3) and short rainy (1.14-1.67). 40 years in Figure 6 with dry spells, drought, and wet years. Dryness persisted for 40 years, causing droughts and impacting agriculture and food security.

Analyses show varied rainfall patterns over time and locations. Some trajectories show upward trends, others downward. In September, rainfall increased in the east, north, and CRV regions (0.14 to 0.29, 0.05 to 0.71, and 0.02 to 0.81 mm per year, respectively) based on Sen's slope estimation. The CRV floor region in Melka, Werer, Abomsa, and Dhera had reduced rainfall of 0.18 to 0.54 mm annually. Most stations showed mixed trends in September. This suggests shorter growing seasons and more terminal droughts.Rainfall main rainy season increased in Adami Tullu, Melkassa, and Abomsa in CRV floor (1.02-2.08 mm/yr), while the Eastern and Northern RV escarpments displayed positive trends (1.21-5.12 mm/yr). Annual rainfall rates declined in Dhera, Matahara, and Melka Werer (0.49-2.25 mm/yr). Sens slope shows increased annual rainfall from 0.042 to 3.88 mm per year in the analyzed regions, but a decline in 5 stations ranging from 1.29 to 3.71 mm/year (Dhera, Matahara, Abomsa, Melka Werer, and Kobbo).

Rainfall data from eleven stations reveal varying planting periods, with growing season start dates ranging from DOY 177(June 5 at Dhera) to DOY 196(July 6 at Mieso) across locations, with CV between 4.9%(Dhera) to 16.6%(Adami Tullu) on CRV floor. Majority of sites (72.7%) begin the growing season in early June (DOY 153) except Almata escapement starting in July (DOY 196). SOS deviation exceeds Reddy's1990 range, hinders pattern understanding, and increases risk. Malkassa on the CRV floor has the earliest end on DOY 274, while Abomsa on the CRV floor has the latest end on DOY 320. Growing seasons ended later in Melkassa and Adami Tullu, but earlier in Dhera and Abomsa. Sirinka's growth period ended one day earlier than Gololcha, Mieso, and Kobbo, with Gololcha arriving six days early. Weather affects crop growth and harvest timing. This study found that the start date of the growing season has changed significantly in most of the regions analyzed over 40 years. 63.6% of the analyzed stations showed a decrease in the start date, while four had an increase. Except for 3 locations, the end of the growing season showed no trend change.The study found that sorghum LGP varied between 78 and 143 days, with CV and SD also varying. Rainy season lengths varied from 24 to 200 days in the examined locations. Onset and cessation showed significant interannual variability. This condition led to variability in LGP. A longer growing period reduces moisture stress and allows for low-risk crop cultivation. Areas in the study cannot grow crops past 90 days without natural rain. LGP varies greatly among studied stations; carefully managed crops for the best output.

Rainy days varied from 67 to 110 across the three regions and 11 stations during the growing season from 1981 to 2021, and ranged from 8.1% to 25.1% . Rainfall varied widely during plant cultivation, with 14-122 rainy days in the region. Adami Tullu, Dhera, Matahara, and Melka Were experienced over 20% variability in rainy days. 63.6% of locations showed no significant upward trend in LGP over 40 years. 36.4% of locations had fewer rainy days and LGP increase (0.02-0.61 per season) and rainy day decrease (0.032-0.74 per season) were observed in the studied regions. LGP decreased, rainy days increased.

Across the studied sites, during the past forty years, the onset, length of the growing season, and number of rainy days varied markedly. In the CRV floor region, the onset, LGP, and the number of rainy days are more variable than in the other two regions. This could be explained by the high interannual variability in the onset and cessation dates in the main rain season, which predisposes the LGP to high interannual variability. At all studied sites, the probability of a dry spell exceeding 5, 7, 10, or 15 days is less than 40% after the first dekadal of June. This probability drops to under 20% at the start of the peak season (June, July, and August), but gradually rises to 40% at the onset of 245 DOY in all stations for dry spells lasting 5, 7, and 10.

The studied climatic parameters and features suggested that the patterns could be difficult to understand, and consequently, decisions on planting dates and related activities were being made in the face of high risk because of the high variability and trend of climate elements. As a result, crop production and performance in the studied locations are greatly impacted by rainfall and temperature variability. Therefore, the region must adopt adaptive mechanisms like cultivating early-maturing sorghum varieties and other crops with a short time of maturity, as well as moisture conservation techniques including rainwater harvesting for supplementary irrigation.

5. Declarations

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Agere Luppi Edao: Data curation, Writing of the original draft.

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Feyera Merga: Data curation, reviewing the original draft

Yibekal Alemayehu: Data curation, reviewing the original draft and

Tewodros Mesfin: Data curation, reviewing the original draft

-6. REFERENCE

Abegaz WB, Abera EA (2020) Temperature and Rainfall Trends in North Eastern Ethiopia. J Climatol Weather Forecast 8:262. doi:10.35248/2332-2594.2020.8.262

Aberra Y. (2012) 'Perceptions of climate change among members of the house of peoples' representatives, Ethiopia', Journal of Risk Research, 15 (7): 771–785.

Agostini A., Bonini M., Corti G., Sani F., Manetti P.; Distribution of Quaternary deformation in the central Main Ethiopian Rift, East Africa, Tectonics, 30, TC4010, doi:10.1029/2010TC002833

Agricultural Transformation Agency (ATA) (2015). Sorghum Sector Development Strategy (Working Document 2015-2020). Agricultural Transformation Agency of Ethiopia (ARTA), Addis Ababa, Ethiopia. Available at: https://www.agriknowledge.org/file_downloads/sb3978325

Alemayehu, A., Bewket, W., 2016. Local climate variability and crop production in the central highlands of Ethiopia. Environ. Dev. 19, 36–48. https://doi.org/10.1016/j. envdev.2016.06.002

Alemayehu, A., Bewket, W., 2017a. Local spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia. Geogr. Ann. Ser. A Phys. Geogr. 99, 85–101. https://doi.org/10.1080/04353676.2017.1289460.

Alemu, M. M., & Bawoke, G. T. (2019). Analysis of spatial variability and temporal trends of rainfall in Amhara region,Ethiopia. Journal of Water and Climate Change, 1–16.https://doi.org/10.2166/wcc.2019.084.

Alexander LV, Zhang X, Peterson TC, Peterson J, Caesar J, Gleason B, Aguil (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111:1–22. https ://doi.org/10.1029/2005 D0062 90

Aragie, E.A. (2013): Climate change, growth, and poverty in Ethiopia. Working paper no. 3.http://mercury.ethz.ch/serviceengine/Files/ISN/165446/ipublicationdocument_singledocument/ad43f694-2a16-458f-bc13 3375b47f622a/en/ccaps+working+paper+no.+3.pdf

Araro, K., Solomon, A., & Dereje, T. (2019). Climate Change and Variability Impacts on Rural Livelihoods and Adaptation Strategies in Southern Ethiopia. J. Earth Systems and Environment. https://doi.org/10.1007/s41748- 019-00134-9.

Araya A, Stroosnijder L (2011). Assessing drought risk and irrigation need in northern Ethiopia.*Agricultural and Forest Meteorology,* 151: 425–436.

Asfaw, A., Simane, B., Hassen, A., Bantider, A., 2018. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: a case study in Woleka subbasin. Weather Clim. Extrem. 19, 29–41. https://doi.org/10.1016/j. wace.2017.12.002.

Asfaw, A., Simane, B., Hassen, A., Bantider, A., 2018. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: a case study in Woleka subbasin. Weather Clim. Extrem. 19, 29–41. https://doi.org/10.1016/j. wace.2017.12.002.attain Pieria Region (Greece); European Water 30 31-40

Ayalew D, Tesfaye K, Mamo G, Yitaferu B, Bayu W (2012).“Variability of rainfall and its current trend in Amhara region,Ethiopia.” African Journal of Agricultural Research, 7(10): 1475-1486

Bekele, D., Alamirew, T., Kebede, A., Zeleke, G. &Melese, A. M.2017. Analysis of rainfall trend and variability for agricultural water management in Awash River Basin, Ethiopia. J. WaterClim. Chang. 5, 127–141

Belay, A.; Demissie, T.;Recha, J.W.; Oludhe, C.; Osano, P.M.;Olaka, L.A.; Solomon, D.; Berhane, Z.Analysis of Climate Variability and Trends in Southern Ethiopia. Climate2021, 9, 96. https://doi.org/10.3390/cli9060096

Box GP, Jenkins GM (1976). Time-series analysis, forecasting and control. Rev. ed., Oakland, California: Holden-Day

Buishand, TA. 1982. Some methods for testing the homogeneity of rainfall records. *Journal of Hydrology*, 58:11-27

Castán Broto V (2020) Climate change, politics, and the urban contexts of messy governmentalities. Territory,Politics, Governance 8(2):241–258. https:// doi. org/ 10. 1080/ 21622 671. 2019. 16322 20

Cheung, W.H.; Senay, G.B.; Singh, A,2008. Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. Int. J. Climatol. J.R. Meteorol. Soc. 2008, 28, 1723–1734.Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield,O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Clara W. Mundia Silvia Secchi , Kofi Akamani and Guangxing Wang ,2019. A Regional Comparison of Factors Affecting Global Sorghum Production: The Case of North America,Asia and Africa’s Sahel. Sustainability 2019, 11, 2135; doi:10.3390/su11072135 www.mdpi.com/journal/sustainability

Conway, D. and E.L.F. Schipper, 2011.Adaptation to climate change in Africa: challenges and opportunities identified in Ethiopia. Global Environmental Change,21(1), 227-237.

Corti .G.. "The Ethiopian rift valley: geography and morphology". CNR-IGG. Retrieved 2013-08-02.

Daron, J.D. (2014) “Regional Climate Messages: East Africa”. Scientific Report from the CARIAA- Adaptation at Scale in Semi-Arid Regions (ASSAR) Project, December 2014.

De Luı´s, M., Gonza´lez-Hidalgo, JC., Raventos, J., Sanchez, JR. and Cortina, J. 1999. Spatial analysis of rainfall trends in the region of Valencia (East Spain). International Journal of Climatology, 20:1451–1469

Degefu W (1987) Some aspects of meteorological drought in Ethiopia.In:GlantzMH(ed) Drought and hunger in Africa. Denying famine future. Press Syndicate of the University of Cambridge, Cambridgea

Demeke, A.B., Keil, A., and Zeller, M. (2011) ‘Using panel data to estimate the effect of rainfall shocks on smallholder’s food security and vulnerability in rural Ethiopia’, Climate Change, 108: 185–206.

Di Falco, S., Yesuf, M., Kohlin, G. and Ringler C. (2012) ‘Estimating the impact of climate change on agriculture in low-income countries: Household level evidence from the Nile Basin, Ethiopia’, Environmental Resource and Economics, 52: 457–478.Dimitrov, R.S. The Paris Agreement on Climate Change: Behind closed doors. Glob. Environ. Politics 2016, 16, 1–11. [CrossRef]

Dinku, T., Connor, S.J., Ceccato, P. and Ropelewski, C.F. (2008) 'Intercomparing of global gridded rainfall products over complex terrain in Africa', International Journal of Climatology, 28: 1627–1638.

Dinku, T., Cousin, R., Corral, J., Ceccato, P., Thomson, M.C., Faniriantsoa, R., Khomyakov, I., Vadillo, A., 2016. Enacts Approach: transforming climate services in Africa, one country at a time. World Policy Pap 1–24.

Dodd, D. and Jolliffe, I. 2001. Early Detection of the Start of the Wet Season in Semiarid Tropical Climates of WesternAfrica. International Journal of Climatology, 21, 1251-1262. http://dx.doi.org/10.1002/joc.640

Duyck, S. The Paris Climate Agreement and the protection of human rights in a changing climate. Yearb. Int. Environ. Law 2015, 26,3–45. [CrossRef].

Edao AL, Kibert K, Mamo G ,2018. Analysis of Start, End and Length of the Growing Season and Number of Rainy Days in Semi-Arid Central Refit Valley of Oromia State, Ethiopia. Adv Crop Sci Tech 6: 386. doi:10.4172/2329-8863.100038

EIAR (2020). The World Bank Available at: http://www.eiar.gov.et/marc/index.php/anrl-research/crop-research.

Eshetu Z., Gebre H. and Lisanework N.,2020. Impact of climate change on sorghum production in North Eastern Ethiopia Afr. J. Environ. Sci. Technol. 49Vol. 14(2), pp 49-43.February 2020

Eshetu, Z.; Simane, B.; Tebeje, G.; Negatu, W.; Amsalu, A.; Berhanu, A.;Bird, N.; Welham, B.; Canales Trujillo, N. (2014): Climate finance in Ethiopia. ODI. http://www.odi.org/sites/odi.org.uk/files/odi-assets/ publications-opinion-files/8995.pdf

FAO (Food and Agriculture Organization) (1984). Assistance with land use planning in Ethiopia:geomorphology and soil. Report prepared and submitted to the Government of Ethiopia.AGDA. ETH/78/003, Field Document 3.

FAO, 2011. The State of Food and Agriculture 2010–2011. FAO, Rome

FAOSTAT. 2015. Statistics for broad beans, horse, beans, dry. Food and Agric. Organization of the United Nations. http://faostat3. fao.org/compare/E (accessed 22 Apr. 2015).

Few, R., Satyal, P., McGahey, D., Leavy, J., Budds, J., Assen, M., Camfield, L., Funk C, Rowland J, Eilerts G, Kebebe E, Biru N, White L, Galu G (2012) A climate trend analysis of Ethiopia. USAID; USGS; FEWS NET, Washington, D.C.

Fitih Ademe, Kibebew K, Sheleme B, Mezgebu G and Gashaw M.2019. Rainfall analysis for rain-fed farming in the Great Rift Valley Basin of Ethiopia. Journal of Water and Climate Change | 11.3 | 2020

Frich P, Alexander LV, Della-Marta P, Gleason B, Haylock M, Tank AK, Peterson T (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim Res 19:193–212

Funk C, Rowland J, Eilerts G, Kebebe E, Biru N, White L, Galu G (2012) A climate trend analysis of Ethiopia. USAID; USGS; FEWS NET, Washington, D.C.

Gebrechorkos SH, Hulsmann S, Bemofer C (2018) Changes in temperature and precipitation extremes in Ethiopia, Kenya and Tanzania. Int J Climatol39:18–30

Gebreegziabher Z, Stage J, Mekonnen A, Alemu A (2011). Climate change and the Ethiopian economy:A computable general equilibrium analysis. Environment for Development Discussion Paper Series, 24 p

Getachew, H., Tesfaye, K. (2015): Analysis of risks in crop production due to climate change in the Central Rift Valley of Ethiopia. – African Journal of Agricultural Research 10(16): 1913-1922.

Getnet, G., MacAlister, C., 2012. Integrated innovation and recommendation domains: Paradigm for developing,scaling-out, and targeting rainwater management innovations. Ecological Economics 76, 34–41.

Girma Mamo. 2005. Using seasonal climate outlook with advice on sorghum production in the Central Rift Valley of Ethiopia. PhD thesis, Blomefontein, Republic of South Africa

Gonzalez-Hidalgo, JC., Lopez-Bustins, J., Stepanek, P., Martin-Vide, J. and De Luis, M. 2009. Monthly precipitation trends on the Mediterranean fringe of the Iberian Peninsula during the second half of the twentieth century (1951–2000). International Journal of Climatology, 29:1415–1429.

Hadgu G, Tesfaye K, Mamo G, Kassa B (2013) Trend and variability of rainfall in Tigray, Northern Ethiopia: analysis of meteorological data and farmers'perception. Acad J Agric Res 1(6):88–100

Hulme M (2011a) Reducing the future of climate: a story of climate determinism and reductionism.Osiris 26(1):245–266.

Hulme M (2020) One earth, many futures, no destination. One Earth 2(4):209–311. https:// doi. org/ 10.1016/j. oneear. 2020. 03. 005

IMF(International monetary fund).2020.Ethiopian statistical Appendix, Washington, DC, IMFcountry report no. 02/214

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis

Irish AID ,2018. Ethiopia Country Climate Risk Assessment Report. Irish AID, Resilience and Economic Inclusion Team, Policy Unit. Available at: climathttps://www.climatelearningplatform.org/change team;%0A.

Jansen, H., Hengsdijk, H., Legesse, D., Ayenew, T., Hellegers, P., Spliethoff, P., 2007. Land and water resources assessment in the Ethiopian Central Rift Valley Alterra Report 1587. Wageningen, the Netherlands

Kang HM. and Yusof F., 2012. Homogeneity tests on daily rainfall series in Peninsular Malaysia. International Journal of Computer and Mathematical Science, 7(1):9 – 22.

Karaburun, A., Demirci, A., Kara, F., 2011. Analysis of spatially distributed annual, seasonal, and monthly temperatures in Istanbul from 1975 to 2006. World Applied Sciences Journal 12, 1662-1675.

Karpouzos D K, Kavalieratou S and Babajimopoulos C 2010 Trend analysis of precipitation

Kassa, F. (2015). Ethiopian seasonal rainfall variability and prediction using canonical correlation analysis (CCA). Earth Sciences,4(3),112119.https://doi.org/10.11648/j.earth.20150403.14

Kassie .B. T., R. P. Rötter, h. Hengsdijk, S. Asseng, M. K. Van ittersum,H. Kahiluoto, and H. Van Keulen,2014. Climate change and agriculture research paper Climate variability and change in the Central Rift Valley of Ethiopia:challenges for rainfed crop production. Journal of Agricultural Science (2014), 152, 58–74. © Cambridge University Press, 2013, doi:10.1017/S0021859612000986

Keir, D., Ebinger, C.J., Stuart, G.W., Daly, E. and Ayele A. Strain accommodation by magmatism and faulting as rifting proceeds to breakup: seismicity of the northern Ethiopian rift, Journal of Geophysical Research, 111(B5), B05314, doi: 10.1029/2005JB003748

Korecha, D., & Barnston, A. G. (2007). Predictability of June–September rainfall in Ethiopia.Monthly Weather Review, 135(2), 628–650. https://doi.org/10.1175/MWR3304.1

Korecha, D., 2014. The current methods and techniques of short, medium, and long-range climate prediction in prediction in Ethiopia. Meteorological Forecast and Early Warning Directorate

Liben F M., 2013.Evaluating RiskAssociEPCCated With Dry Soil Planting Of Sorghum [Sorghum Bicolor (L.) Moench] And Maize (Zea Mays L.) At Different Depths In Predictable Onset Of Rain In The Central Rift Valley, Ethiopia M.Sc. Thesis submitted to school of Graduate Study ,HramayaUniversity,Ethiopia

Mekasha A., Tesfaye K., and Duncan A.J. (2014) 'Trends in daily observed temperature and precipitation extremes over three Ethiopian eco-environments', International Journal of Climatology, 34(6): 1990-1999.

Mensah, C., Amekudzi, L.K., Klutse, N.A.B., Aryee, J.N.A. and Asare, K.,2016.Comparison of Rainy Season Onset, Cessation and Duration for Ghana from RegCM4 and GMet Datasets. Atmospheric and Climate Sciences, 6,300-309. http://dx.doi.org/10.4236/acs.2016.62025

MOARD (Ministry of Agriculture and Rural Development), 2006 rural development strategies MOARD , Addis Abeba,Ethiopia.

MOEF(Ministry of Environment and Forest) (2015). Ethiopia's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). The Federal Democratic Republic of Ethiopia. URL: https://unfccc.int/resource/docs/natc/ethnc2.pdf

Mugalavai, E. M., Kipkorir, E. C., Raes, D., & Rao, M. S. (2008). Analysis of rainfall onset,cessation, and length of growing season for western Kenya. Agricultural and ForestMeteorology, 148 (6–7), 1123–1135. https://doi.org/10.1016/j.agrformet.2008.02.013.

Muluneh Alemayehu, Saskia Keesstra, and Leo Stroosnijder ,2017.Bridging dry spells for maize cropping through supplemental irrigation in the Central Rift Valley of Ethiopia. Land Degradation and Development

Mupangwa, S. Walker, S. Twomlow, 2013. Start, end and dry spells of the growing season, insemi-arid, southern Zimbabwe

Murken, L., Cartsburg, M., Chemura, A., Didovets, I., Gleixner, S., Koch, H., Lehmann, J., Liersch, S., Lüttringhaus, S., Rivas López, M. R., Noleppa, S., Roehrig, F., Schauberger, B., Shukla, R., Tomalka, J., Yalew, A. & Gornott, C., 2020. Climate risk analysis for identifying and weighing adaptation strategies in Ethiopia's agricultural sector. A report prepared by the Potsdam Institute for Climate Impact Research for the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development, 150 pp. DOI: 10.2312/pik.2020.003

Murtaza, G., Javed, S., Dong, Y., & Usman, M. (2019). An inclusive assessment on the correlation between agriculture and climate change. International Journal of Chemistry Studies. ISSN: 2581-348X; www.chemistryjournal. 3(2):35-42.

NAP(National Adaptation Plan),2019 Ethiopia's Climate Resilient Green Economy

National Meteorological Agency (NMA) (2001). Report submitted to the initial national communication of Ethiopia to the United Nations Framework Convention on Climate Change (UNFCCC), Addis Ababa, Ethiopia

Ngetich K. F.M.Mucheru-Muna, J. N.Mugwe, C. A. Shisanya, J. Diels, and D. N.Mugendi,2014 "Length of growing season, rainfall temporal distribution, onset and cessation dates in the Kenyan highlands," Agricultural and ForestMeteorology, vol. 188,pp. 24– 32, 2014

Ngongondo, C., Yu-Xu, C., Gottschalk, L., and Alemaw, B. 2011. Evaluation of spatial and temporal characteristics of rainfall in Malawi: a case of data scarce region. Theoretical Application in Climatology, 106:79-93.

Nicholson, S. E. (2017), Climate and climatic variability of rainfall over eastern Africa, Rev. Geophys., 55,590–635, doi:10.1002/2016RG00054489.Oliver, J.E., 1980. Monthly precipitation distribution: a comparative index. Prof. Geogr. 32, 300–309..

Oliver, J.E., 1980. Monthly precipitation distribution: a comparative index. Prof. Geogr. 32, 300–309.

Omondi, P.A. et al. (2014) 'Change in temperature and precipitation extremes over the greater Horn of Africa region from 1961 to 2010', International Journal of Climatology, 34: 1262-1277

Parry M. L, Canziani O. F, Palutiko J. P, V Linden V, Hanson C. E (2007). Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,. IPCC Technical report. UK, Cambridge University Press: 23-77

Partal T. and Kahya E. 2006. Trend analysis of Turkish precipitation data. *Hydrology Processes*, 20:2011–2026. DOI: 10.1002/hyp.5993.

Reddy, S. J. 1990.Methodology: Agro-Climatic Analogue Techniqueand Applications as Relevant to dry Land Agriculture. AgroClimatology Series 86/21-WMO/UNDP, NMSA.

NationalMeteorology Service Agency (NMSA), Addis Ababa,Ethiopia.

Saroar, M.M.; Leal Filho, W. Adaptation through climate smart agriculture: Status and determinants in coastal Bangladesh.In Climate Change Adaptation, Resilience and Hazards; Springer: Cham, Switzerland, 2016; pp. 157–17

Schlenker, W., Lobell, D.B., 2010. Robust negative impacts of climate change on African agriculture. Environ. Res. Lett. 5, 1–8. https://doi.org/10.1088/1748-9326/5/1/ 014010.

Seleshi Y.and U. Zanke, "Recent changes in rainfall and rainy days in Ethiopia," International Journal of Climatology, vol. 24,no. 8, pp. 973–983, 2004

Shafer, M. (2017). Climate Change Primer: What do you need to know? A clear and concise explanation about climate change and global warming. Thailand. info@warmheartworldwide.org

Solomon T., Kindie T., Girma Mamo.2015.ANALYSIS OF RAINFALL AND TEMPERATURE VARIBILITY TO GUIDE SORGHUM (SORGHUM BICOLAR) PRODUCTION IN MIESSO AREAS, EASTERN ETHIOPIA. International Journal of Agriculture research 2017Vol.2,No11.pp1-11ISSN(e)2313

SONWA DJ, DIEYE A, EL MZOURI EH, MAJULE A, MUGABE FT, OMOLO N, WOUAPI H, OBANDO J And BROOKS N (2017) Drivers of climate risk in African agriculture. Clim. Dev. 9 (5) 383– 398. https://doi.org/10.1080/17565529.2016.1167659

Stern, R. D., Dennett,M.D.&Dale, I. C. 1982. Analyzing daily rainfall measurements to give agronomicall useful results. I. Direct methods. Experimental Agriculture18,223–236.

Stern, R., Rijks, D., Dale I. and Knock, J. 2006. INSTAT Climatic Guide. Reading, UK:Statistical Services Centre, the University of Readi

Stern, R.D.& Cooper, P. J. M. (2011). Assessing climate risk and climate change using rain fall data–a case study from Zambia. Experimental Agriculture 47, 241–266

Swarup, A.; Dankelman, I.; Ahluwalia, K.; Hawrylyshyn, K. (2011):Weathering the storm: Adolescent girls and climate change.Plan.http://www.planuk.org/resources/documents/35316/

Tabari, H., Meron, T. T., & Willems, P. (2015). Statistical assessment of precipitation trends in the upper Blue Nile River basin. Stochastic Environmental Research and Risk Assessment, 29(7),1751–1761. https://doi.org/10.1007/s00477-015-1046–0

Tesfaye, K. and Walker, S., 2004. Matching of crop and environment for optimal water use the case of Ethiopia. Physics and Chemistry of the Earth, 29(15-18):1061-1067.

Teshome, H.; Tesfaye, K.;Dechassa, N.; Tana, T.; Huber, M.Analysis of Past and ProjectedTrends of Rainfall and Temperature Parameters in Eastern and Western Hararghe Zones, Ethiopia.*Atmosphere* **2022**, *13*, 67.https://doi.org/10.3390/atmos13010067

The World Bank,2020. Climate Risk Profile: Ethiopia (2020): The World Bank Group.

The World Bank,2021. Climate Risk Profile: Ethiopia (2021): The World Bank Group.

Tilahun K., 2006"Analysis of rainfall, climate, and evapo-transpiration in arid and semi-arid regions of Ethiopia using data over the last half century," Journal of Arid Environments, vol. 64, no. 3, pp.474–487, 2006

Trnka, M., Olesen, J.E., Kersebaum, K.C., Skjelvåg, A.O., Eitzinger, J., Seguin, B., Peltonen-Sainio, P., Rötter, R., Iglesias, A., Orlandini, S., 2011. Agroclimatic conditions in Europe under climate change. Global Change Biology 17, 2298-2318.

UNDP Ethiopia 2018, Framework for UNDP Ethiopia's Climate Change,Environment and Disaster Risk Management Portfolio

UNFCC (2011) Fact Sheet: Climate Change Science—The Status of Climate Change Science Today. United Nations Framework Convention on Climate Change, New York.

USAID(The United States Agency for International Development),2015ClimateChangeAdaptation, Thought Leadership and Assessments (ATLAS)

USAID. 2016b. USAID Climate Risk Screening Tool for Ethiopia. August. [Note: this is unpublished. The draft from Alex Apotsos was reviewed by the Assessment Team]

Vergni, L., Todisco, F., 2011. Spatio-temporal variability of precipitation, temperature, and agricultural drought indices in central Italy. Agricultural and Forest Meteorology 151, 301-313.

Wagaye B A, Antensay M 2020. Rainfall Variability and Trends over Central Ethiopia. Int JEnviron Sci Nat Res. 2020; 24(4): 556144. DOI: 10.19080/IJESNR.2020.24.556144 0225

Wagaye Bahiru, Eshetu Zewdu,2021. Analysis of Spatial and Temporal Climate Characteristics in North Eastern Ethiopia: Case Study of North Wollo Zone. International Journal of Energy and Environmental Science. Vol. 6, No. 3, 2021, pp. 57-67. doi: 10.11648/j.ijees.20210603.12

Wing H. Cheung, Gabriel B. Senay and Ashbindu Singh (2008). Trends and spatial distribution of annual and seasonal rainfall in Ethiopia, INTERNATIONAL JOURNAL OF CLIMATOLOGY Int. J. Climatol. 28: 1723–1734 (2008) Published online 5 March 2008 by Wiley Inter Science, DOI:10.1002/joc.1623

World Bank (2010): Economics of Adaptation to Climate Change: Ethiopia. http://www-

Yenigun K, Gumus V, Bulut H (2008). Trends in stream flow of the Euphrates basin, Turkey.Proceedings of the Institution of Civil Engineers Water Management. 161, 189–198. Doi:10.1680/wama.2008.161.4.189

You, G.J.Y; and Ringler, C. (2010): Hydro-Economic Modeling of Climate Change Impacts in Ethiopia. IFPRI Discussion Paper 00960.