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Research Article

Rainfall Characterization over Western Amhara, Ethiopia

Behabtu Gobeze Mengiste[1,*], Temesgen Admasu Yazachew[2]

[1]Department of Environment and Climate Change, Ethiopia Road Administration, Addis Ababa, Ethiopia
[2]Department of Social Development, Ethiopia Road Administration, Addis Ababa, Ethiopia

Abstract

Climate change has intensified rainfall variability across Sub-Saharan Africa, posing significant threats to smallholder farmers who rely on rain-fed agriculture for their livelihoods. Ethiopia, and particularly the Amhara region, is among the most vulnerable areas due to its dependence on seasonal rainfall and diverse topography. Despite numerous studies, findings on rainfall variability across Ethiopia remain inconsistent, underscoring the need for localized assessments. This study investigates rainfall characterization in western Amhara, Ethiopia, focusing on onset, cessation, length of growing period (LGP), and variability over the period 1992–2021. Data from 11 meteorological stations were analyzed using the Climate Data Tool (CDT), supported by quality control methods to address missing values, outliers, and homogeneity issues. The results indicate that the mean rainfall onset in western Amhara occurs on May 28 (Day of Year 148), with early and late onsets ranging between May 3 and June 30. The mean cessation date is September 29 (Day of Year 272), varying from July 14 to October 15 across stations. Consequently, the mean LGP is 124 days, with ranges from 103 to 151 days, reflecting both interannual and spatial variability. Stability analysis revealed high consistency in onset and LGP (standard deviations of 11 and 13 days, respectively) and very high stability in cessation dates (SD = 4 days). Annual total rainfall ranged between 995 mm and 1783.5 mm, with a mean of 1316.7 mm and coefficient of variation (CV) of 14.4%. Seasonal *Kiremt* rainfall averaged 1002 mm, with CV values of 15.6%, highlighting moderate variability. Compared to previous studies, this research observed shorter growing periods, pointing to emerging challenges for crop production under shifting climatic conditions. The study emphasizes the importance of localized rainfall analysis for agricultural planning, food security, and climate adaptation. Findings provide critical insights for farmers in timing planting and harvesting, while also supporting policymakers in designing targeted interventions for resilience. It is recommended that future work expand the network of meteorological stations, enhance community-based monitoring, and foster interdisciplinary collaboration to improve adaptation strategies. Ultimately, understanding rainfall dynamics in western Amhara is essential for ensuring sustainable agricultural productivity and resilience in the face of climate variability.

Keywords

Cessation, Length of Growing Period, Onset, and Western Amhara

[*]Corresponding author: behabtsh2011@gmail.com (Behabtu Gobeze Mengiste)

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1. Introduction

1.1. Background of the Study

Climate change is one of the most pressing global problems since the beginning of the industrial revolution it has been associated with the increasing trend in carbon dioxide and other greenhouse gases (GHGs) in the atmosphere, presenting a critical challenge, especially in rural communities heavily reliant on seasonal weather conditions for their livelihoods [1]. Smallholder farmers in Africa are particularly vulnerable to the impacts of climate change [2].

Projections indicate that by the end of the twenty-first century, climate change could lead to a median temperature increase of 1.4–5.5 ℃ and a median precipitation increase of 2–20% in East Africa [3], resulting in an overall decrease in the production of staple crops [4] by shortening the length of the growing season, intensifying water stress, and increasing the frequency of pest and disease outbreaks [5]. In Ethiopia, where rain-fed agriculture dominates, insufficient precipitation and accompanying drought are major contributors to hunger and food scarcity [6].

Ethiopia currently stands as one of the most vulnerable countries to the impacts of climate change and variability [7]. However, studies on rainfall variability and trends in Ethiopia have yielded inconsistent results due to the country's diverse geographical and topographical features [8]. Rainfall trends vary from region to region, with some studies reporting decreasing trends while others show increasing trends or both in different areas [9, 10]. Conversely, other studies have shown an increasing trend in annual rainfall [11]. Other studies revealed both an increasing and decreasing rainfall trend in different areas [12].

In western Amhara, Ethiopia, rainfall trends exhibit both increasing and decreasing patterns, with a predominant monomodal nature characterized by long rains during the *Kiremt* season [13] Accurate knowledge of rainfall onset and cessation dates is crucial for farmers and planners to make informed decisions regarding crop selection and planting schedules, as well as to mitigate potential crop yield losses [14].

Access to baseline data on rainfall intensity, distribution, and onset dates is essential for farmers to avoid confusion, seed losses, and reduced crop yields due to mistimed planting [15]. Changes in the length of the growing season may also impact animal species, crop types, invasive species, and irrigation needs, while rainfall timing can influence disease transmission by affecting the life cycles of disease vectors.

Annual and seasonal rainfall information is indispensable for addressing social and economic challenges faced by farmers dependent on rainfall for their agricultural activities. However, in a changing climate, traditional reliance on prior weather knowledge may no longer suffice. Therefore, research on climate change and rainfall variability is crucial for improving agricultural management practices, developing adaptation strategies, and enhancing resilience among farming communities [16].

In light of these considerations, this study aims to estimate the trend and characterization of rainfall, including onset, cessation dates, length of growing period (LGP), and rainfall variability, in western Amhara from 1992 to 2021.

1.2. Statement of the Problem

In Sub-Saharan Africa, agriculture is the key economic sector for reducing poverty and achieving the attainment of food security [17]. Similar to this, it also plays a crucial role in Ethiopia's development, providing the output needed to feed a growing population, in the industrialization and overall transformation of the broader economy that accounts for about 40% of the country's gross domestic product and nearly 70% of its employment [18].

Generally in the Amhara region Ethiopia, the risks of climate variability that smallholders face are brought on by a lack of regional/local climatic information, lack of adaptable capability, and limited adaptation options [19]. To that end, numerous studies have been conducted in different parts of Amhara district related to the characterization of rainfall. [20] in the North Eastern Amhara Region, Ethiopia revealed that the annual and seasonal *Kiremt* rainfall totals were characterized by low amounts, short Length of growing period, early cessation, and high dry spell probabilities.

Taye, Zewdu [13] Found variability in rainfall onset, cessation, and length of growing period in western Amhara. Their study used five stations, recommending increasing the number of stations to improve the precision and reliability of findings. Also, [21] stated that research on rainfall variability and trends at a local level (in a smaller region with higher resolution) has huge advantages; it aids decision-makers in taking appropriate measures.

Previous studies in Ethiopia [22] have not utilized the CDT tool which is an open-source R-based program with a simple graphical user interface for analyzing meteorological data. This applies to data quality and data analysis, which enhances the accuracy of the result. Second, most studies are conducted at broader scale such as [23] *Kiremt* rainy season over Ethiopia from 1943 to 1999. Studies on the timing and trend of rainfall at the national level may not accurately reflect localized timing and trend of rainfall. This is due to the country's varied altitude and complicated topography [24]. However, No detailed studies have been conducted on the timing of rainfall in the country, particularly in Western Amhara. Hence, this study seeks to fill this gap by characterizing rainfall timing, variability, and trends in Western Amhara to support evidence-based decision-making and improve climate-resilient agricultural practices.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of the study was to examine the rainfall Characterization, from the period 1992-2021 over Western Amhara, Ethiopia.

1.3.2. Specific Objectives

To assess the pattern of rainfall onset and cessation for western Amhara Ethiopia from the 1992-2021 time period.

To estimate the length of growing period for western Amhara Ethiopia from 1992–2021.

1.3.3. Research Questions

What was the pattern of rainfall onset and cessation in western Amhara Ethiopia from the 1992-2021 period?

What was the estimate of the length of the growth period in the study area from 1992 to 2021 period?

1.4. Significance of the Study

Studying rainfall characterization over Western Amhara, Ethiopia holds significant importance due to its direct impact on agricultural practices, water resource management, and climate change adaptation strategies in the region. Firstly, rainfall patterns profoundly influence agricultural productivity, as agriculture serves as the primary livelihood for many residents of Western Amhara. Understanding the characteristics and trends of rainfall enables farmers to make informed decisions regarding crop selection, planting schedules, and water management practices, thereby enhancing agricultural yields and ensuring food security for the local population. Additionally, by analyzing rainfall data, stakeholders can develop tailored agricultural interventions and adaptation measures to mitigate the adverse effects of climate variability on crop production and livelihoods.

Secondly, rainfall trend analysis plays a crucial role in water resource management, particularly in a region like Western Amhara, where water scarcity and droughts are prevalent challenges. By studying rainfall patterns, policymakers and water managers can better predict water availability, optimize water allocation, and enhance the efficiency of irrigation systems. This enables sustainable use of water resources, minimizes the risk of water-related conflicts, and promotes resilience to droughts and other weather-related disasters.

Thirdly, studying rainfall characteristics is essential for developing effective climate change adaptation strategies in Western Amhara. This information allows policymakers, development agencies, and community stakeholders to design and implement adaptation measures that enhance resilience to climate impacts, protect vulnerable communities and ecosystems, and promote sustainable development. Ultimately, by understanding and responding to the changing dynamics of rainfall in Western Amhara, stakeholders can build more resilient and adaptive communities capable of thriving in a changing climate.

1.5. Scope and Limitations of the Study

The general objective of the study was to examine the rainfall Characterization over Western Amhara, Ethiopia. Spatially, the study covers 11 metrological stations found in west Amhara (Bahir dar, Gonder, Debretabor, Dangla, Debre markos, Metema, Motta, Nefassmewucha, Debre work, Aykel, and Chagni) from the period 1992 to 2021. The station was chosen based on the availability of daily and long-term rainfall data, data quality, and being representative of the study area. It could be representative of different climate zones. Methodologically, the study used climate data tool (CDT) was employed to identify the onset and cessation of rainfall.

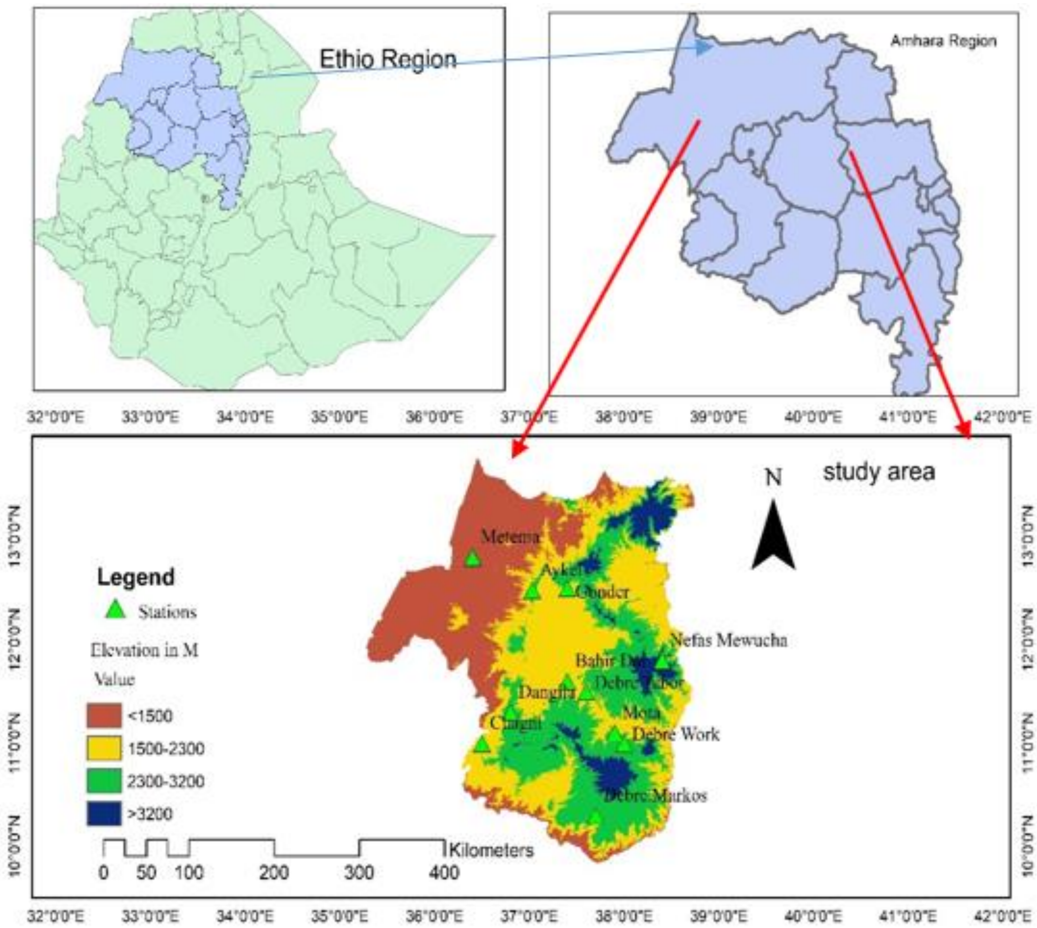
In the course of the research, several problems were encountered. The first was the uneven distribution of meteorological stations and missed data. The data-filling technique was used to overcome missed data. To overcome uneven distribution of meteorological stations, the researcher tried to select a representative station by considering the quality of the data and its availability.

2. Methodology

2.1. Descriptions of the Study Area

Amhara region is one of the regional states in Ethiopia and is located in the northwestern part of the country. It has around 20 million people, of which more than 82 percent reside in rural areas [25]. Geographically, it lies between Amhara region and is located between Latitude: 11° 20’ 57.929" N and Longitude: 37° 58’ 42.451" E. Its area is estimated at 170,000 square kilometers and is divided into 11 administrative zones. Elevation ranges from 700 m to 4,620 m a.s.l. The western part of Amhara has the lowest elevation, while the eastern and northeastern parts have the highest elevations. Most of the region is on the highland plateau above 1,500 m and is characterized by rugged mountains, hills, valleys, and gorges. The majority of the population in the region depends heavily on rain-fed agriculture for their livelihoods. The region is characterized by erratic rainfall, and high rate of poverty [26]. Erratic rainfall patterns and frequent extreme events cause crop failure and threaten the food security and livelihoods of the people in the region. Therefore, knowledge of characterization in the region helps the local community to better plan sustainable adaptation and secure sustainable agricultural production.

Majorly as a result of natural hazards, uneven rainfall distribution, land degradation, and pest damage, all of which are related to climate variability. In the region as a whole, 2-3 million people face severe food insecurity, making up one-third of all vulnerable and chronically starving populations in the country's [7] The mean annual temperature of the region ranges from 15 ℃ and 21 ℃. But in the valleys and marginal areas the temperature exceeds 27 ℃. There are different ways of classifying the climatic systems of Ethiopia, including the traditional, the Köppen’s, the Throthwaite’s, the rainfall regimes, and the agro-climatic zone classification systems [27]. The most frequently used classification systems are the traditional and the agro ecological zones (AEZs). According to the traditional classification system, which mainly depends on altitude and temperature this divides into five categories based on altitude and temperature. These are *Bereha* (hot lowlands <500 meters), *Kolla* (lowlands, 500-1500 meters), *Woina Dega* (midlands, 1500-2300), Dega (highlands, 2300-3200), *Wurch* (highlands, 3200-3700) and Kur (highland, >3700). The population of the region comprises 25.5 percent of the total population of the country, while in terms of area, the region contributes only 15.4 percent [28]. Consequently, if the current trend in population growth continues, the population size of the region would double within 25 years. In terms of settlement patterns, almost all, approximately 89 percent of the population, reside in rural areas and are primarily engaged in agriculture. The highlands are more densely populated than the lowlands.



Source Ethio- region shape file

Figure 1. *Map of the study area and location of meteorology stations.*

2.2. Research Design

Descriptive research design was used to conduct this research. A descriptive research design aims to identify characteristics of rainfall. A quantitative research approach was used to consider numeric data.

Secondary data was used from Ethiopia's Meteorology Institute, the main office found in Addis Ababa, which is long-term record of daily rainfall data. To select meteorological stations located in the study area, purposive sampling method was used based on the availability of daily data, long-year rainfall data, quality, and being representative of the study area.

2.3. Data Sources and Data Collection

Daily rainfall and minimum and maximum temperature data for eleven stations: Bahir Dar D/markos, Motta, Dangla, D/tabor, Gonder, Metema, Nefassmewucha, D/work, Aykel, and Chagni were obtained from the main office of Ethiopia's Meteorology Institute found in Addis Ababa to show the characterization of rainfall over western Amhara from 1992-2021. WMO suggested 30 years and above, hence 30 years of data were utilized to examine western Amhara [29].

Table 1. *Description of the study meteorological stations.*

	Station	Latitude	Longitude	Elevation in m	Year of observation
East Gojjam	Debre-markos	10 °20'	37 °43'	2446	1992-2021
	Motta	11 °5'	37 °5'	2417	1992-2021
	Debre-work	10°66′	38° 16′	2508	1992-2021
Awi zone	Dangila	10 °16'	36 °56'	2116	1992-2021
	chagni	10°95′	36° 5′	1614	1992-2021
South Gondar	Debretabor	11°51′	38°10′	2613	1992-2021
	Nefassmewucha	11°81′	38° 36′	3098	1992-2021
North Gondar	Gonder	12 °6'	37 °46'	1973	1992-2021
	Aykel	12°48′	37°03′	2254	1992-2021
	Metema	12°58′	36°12′	790	1992-2021
West Gojjam	Bahir dar	11 °36'	37 °23'	1800	1992-2021

Source: Ethiopia Meteorology Institute

2.4. Sampling Techniques

Meteorological stations were purposively selected, based on the availability of daily rainfall, minimum temperature and maximum temperature data, and fair distribution of the station in the study area. Quality, long-year rainfall data, and being representative of the study area.

2.5. Missing Data

Missing data is one of the major issues that frequently arise in meteorological analysis. It may be caused by absence of an observer, equipment failure or breakage, and due to conflict or a wide range of factors. When data are missing, it may be useful to fill these data sets from observations made in other nearby and reliable stations. Additionally, the missing data were filled with gridded data, arithmetic average method, and climatological mean of the day.

Mathematically: -

Arithmetic average method

If the normal annual rainfalls at nearby gauges are within 10% of the normal annual precipitation at the stations concerned, then the arithmetic procedure could be used to estimate the missing data [30]. It is fast and easy to calculate because its calculation is straightforward and its meaning is known to everybody, arithmetic average is also more comfortable to use as input for further analyses and calculations. But Sensitive to extreme values.

This method is used when normal annual precipitations at various stations show variation within 10% w. r. t station X.

The annual precipitation values at neighboring stations are P1 (station 1) P2(Station 2), P3 (Station 3), …. Pm (Station M).

To determine annual precipitation $P_{X \text{ at}}$ station X.

$$P_X = \frac{1}{?}(P_1 + P_2 + \cdots P_?) \tag{1}$$

The climatological mean of the day (CMD).

This technique utilizes the long-term average value of the same day of interest V_{est} is the estimated value, V_i is the value of the variable for the i^{th} day of year j, and T is the number of years data are available [31].

The output of Eq. 2 is simply a temporal average of the j^{th} day value

$$V_{est,i} = \frac{\sum_{j=1}^{T} V_{ij}}{T} \tag{2}$$

2.6. Data Quality Control

There were some missing values in the observed data obtained from the Ethiopian Meteorology Institute most missing values were filled at the source. However, some rainfall station data are missed; for example, Chagni from

1993–97, Debre-markos 1993 (12–25 days), Debre-work 2009 from February to October, Nefasmewucha 2007 and 2008 January and May are missed, and Dangla 1992 May month is missed. To complete such values, a simple gap-filling method is used, which is called the climatological mean of the day [32], Arithmetic average method, and gridded data were used. a very small number of temperature data exchanges of values, maximum with minimum temperature, and reciprocally, and have no missing value shown.

Outliers are observations that deviate from or are disproportionally different from the rest of the data [33]) and could be caused by problems such as instrumentation error, human error, and changes in the environment. Because outliers could affect the quality of the data and the results of analysis, excluding them from the data set is a crucial activity. There are numerous outlier detection techniques have been developed [34]. The Enhancing National Climate Services (ENACTS) initiative of the International Research Institute for Climate and Society Columbia University, has been addressing these data quantity and quality gaps it develops the Climate Data Tool (CDT).

The overall process for quality checks implemented in CDT includes the following steps:

1) Checking for station coordinates

It would be difficult to automatically check for the accuracy of the coordinates of a given station. This is done by checking whether the station coordinate is within the country boundary or not. It also displays the location of the stations on Google Maps. CDT can also check for duplicate and missing coordinates, which happen frequently [35].

2) Outliers check

There are various techniques for identifying outliers or suspicious observations. The methods implanted in CDT include limit check, internal consistency check, temporal check, and spatial check [35].

Limit check involves comparing observation to previously define upper and lower limits of the specific element for the specific climate.

In internal consistency to determine whether there is physical and climatological consistency between two observations, internal consistency entails comparing the observation to other meteorological parameters. It is done either for the time the observation denotes or for the time series. As some of the meteorological parameters are physically related, checking the consistency between these variables informs us about whether the observation is an outlier or not.

Temporal consistency checks when comparing an observation from a given station for a certain month to the long time series for that particular month, temporal consistency is used to determine whether the difference is significant this test is based on the fact that many climatological variables show significant serial correlation. In CDT, this comparison is done for each of the 12 months separately to make sure data from climatological periods check for homogeneity of climate time series.

The spatial check makes comparisons between the observation and information from surrounding stations or between the expected value for the station in question and information from nearby stations. It can be done using interpolation either by checking against numeric values calculated based on the values from surrounding stations, or by comparing statistics. The data that considerably deviate from the anticipated values are marked as potential outliers.

The CDT outlier test indicated that precipitation data of some Meteorological stations (Chagni, Motta, Debretabor,) had some very small numbers of outliers. Most of the outliers occurred during data entry, and some of the outliers were tolerated and taken as normal data. See Figure 6 to Figure 12.

3) Homogeneity test

If a climate time series is homogeneous over a longer period, it can be determined using homogeneity checks. The two basic components of the homogenization of climatic data are as follows: identifying breaks and adjusting the particular segment for inhomogeneity [36]. For detecting breaks in a climate time series, the CDT provides four methods. The primary approach is the Pettit test, which is a nonparametric rank-based method used to identify changes in the mean value of the distribution of the variable under study [37] The other approach adopted in CDT is the normal standard test (SNHT) [38]. The other two methods rely on the cumulative sum (CUMSUM) approach with and without trends [39].

CDT offers two techniques for adjusting in homogeneity mean and quantile matching. Quantile matching compares quantiles before and after the break while the mean method compares the mean before and after the break [36].

When evaluating the homogeneity of climate data in climate research, the Standard Normal Homogeneity Test (SNHT), Pettit-nonparametric test, and Buishand Range Test are commonly used [33, 40].

Normal Homogeneity Test (SNHT), the test was used to check the homogeneity of time series data (temperature and precipitation).

As illustrated in the appendix Figure 13 to Figure 23, the appendix presents homogeneity tests. The monthly rainfall of six stations (Aykel, Chagni, Debre markos, Debre work, Dangila, and Motta) stations was homogeneous and Bahir dar, Debre Tabor, Gonder, Nefassmewucha and Metema had a single break in SNHT homogeneity tests.

2.7. Method of Data Analysis

This study used the Climate Data Tool (CDT) version 7.0, R programming, and Excel 2013 to conduct statistical analysis of the meteorological data for the study area. CDT is an open-source R-based program with a simple graphical user interface for analyzing meteorological data. The primary functions of CDT include station data organization, quality control, and processing; estimates and the reanalysis of data [41].

The CDT tool was developed to address critical gaps in climate services and applications, particularly in Africa [42, 43] This occurs as a result of a problem with access to and availability of climatic data.

2.7.1. Onset and Cessation of Rainfall

The onset and cessation dates are the days of the year when rainfall starts and ends [44]. Climate Data Tool (CDT), an open-source R-based software that comes with an intuitive and user-friendly graphical user interface (GUI) was used to identify the beginning and end of rainfall. There are a considerable number of definitions and thresholds for calculating rainfall onset and cessation date patterns in the literature. The first and most used methods in literature are those apply threshold values on Total rainfall amount e.g. [45].

In this study, rainfall onset was determined by thresholds of the rainy day at least 1 mm, accumulated rainfall total of 20 mm over 5 days with at least 3 consecutive rainy days, and dry spell not exceeding 7 days in the next 21 days [46]. According to NMSA (2001), a day is said to be dry if it accumulates rainfall<1 mm, and dry spell length is the maximum number of consecutive dry days with rainfall less than 1 mm per day exceeding 5, 7, 10, and 15 [50].

The rainfall cessation date is computed based on the fraction of evapotranspiration and the threshold used is accumulated 10 days of rainfall less than 0.5 of evapotranspiration [47].

PET (potential evapotranspiration) was used to calculate the cessation of the rainfall. Accumulated 10 day's rainfall less than 0.5 of the evapotranspiration. CDT offers 2 methods to compute the PET: Hargreaves [48, 49] which only uses the minimum and maximum temperatures; and Modified Hargreaves [50] with which the precipitation data is used in addition to the minimum and maximum temperatures. In this study Modified Hargreaves was applied to calculate the potential evapotranspiration

$$\mathrm{PET}{=}\alpha * 0.408 * R_A \left(\frac{\mathrm{T_{min}+T_{max}}}{2} + \mathrm{b}\right) (\mathrm{T_{max}} - \mathrm{T_{min}}\ ) - \mathrm{c} * \mathrm{p})^{0.5} \tag{3}$$

Where

1) R_A is the incoming solar radiation (in W/m2),
2) Tmin and Tmax are the minimum and maximum temperatures (in ℃),
3) P is the precipitation data (in mm/day),
4) PET is expressed in mm/day,
5) The coefficients a, b, c, and d depend on the temporal resolution of the data.

2.7.2. Length of Growing Period

The onset and cessation dates are the day of the year when rainfall starts and ends. The difference between the onset and cessation dates is the length of the growing season ends [44]. The length of growing period is the Duration of the rainy season.

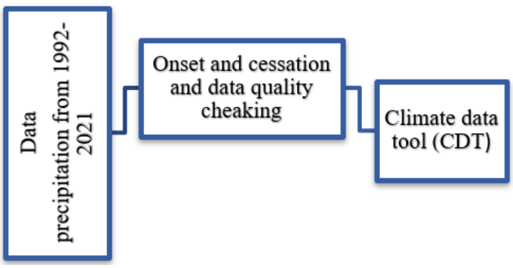


Figure 2. *Methodological framework of the study.*

3. Results and Discussion

3.1. Rainfall Onset

In this study, the mean onset dates of Bahir Dar, Motta, Debre Markos, and Dangla were 152,153,142 and 137. However [13] conducted in western Amhara Ethiopia the mean onset date of Bahir Dar, Motta, Debre Markos, and Dangla was; 153,151, 144, and 132 DOY (Day of the year starting from January first), respectively which is almost similar. The mean onset date of western Amhara varied from (May -16) to (June-10). This study concluded that the mean onset date of western Amhara Ethiopia is May 28, while Dereje *et al*. (2012) reported the average date of beginning for *Kiremt* rains in the Amhara National Regional State as June 15. The early and late-onset dates of the western Amhara Ethiopia are May 3 and June 30, respectively.

The stability of the onset date of rainfall for western Amhara, Ethiopia is highly stable (SD=11). If one standard deviation of the mean it means that 68% of the onset date of the rainfall falls between May 17 to June 9. If 2 standard deviations of the mean it means that 95% of the Onset date of the rainfall fall between May 6 to Jun 20.

See Table 3 for the onset date of the rainfall in western Amhara study meteorological station and Figure 24(a-k) in the appendix presents the rainfall onset of each station over western Amhara, Ethiopia.

The *Kiremt* (long) rainy season typically begins in the western Amhara region of Ethiopia around June and extends through September. This period marks the primary rainy season in Ethiopia, characterized by widespread and relatively consistent rainfall.

In the western Amhara region, including areas such as Bahir Dar, Gondar, and surrounding districts, the onset of the *Kiremt* rains usually occurs in June. However, the exact timing can vary slightly from year to year and within different parts of the region.

The onset of the *Kiremt* rains is critical for agriculture in the western Amhara region, as it coincides with the main planting season for crops such as maize, teff, sorghum, and millet. The rainfall during this period replenishes soil moisture, supports crop growth, and contributes significantly to agricultural productivity in the region.

Local meteorological agencies, as well as international organizations and research institutions, monitor and analyze rainfall patterns in the western Amhara region to provide early warning information and support agricultural planning and decision-making. By understanding the onset and characteristics of the *Kiremt* rains, farmers and policymakers can better prepare for the agricultural season and mitigate the impacts of climate variability on crop production and food security in the region.

Table 2. *Characteristics of kiremt season for western Amhara Ethiopia.*

Rain Fall Characteristics	Standard Deviation (SD)	Stability
The onset of Kiremt rainy season For Western Amhara	11	High stability
Cessation of Kiremt rainy season For Western Amhara	4	Very high stability
Length Of Growing Period For Western Amhara	13	High stability

Table 3. *Onset date of the rainfall in western Amhara study meteorology station.*

ID. STN	Aykel	Bahir Dar	Chagni	Debre Mark	Debre Wor	Dangila	Debre Tabo	Gonder	Nfas Mewuc	Metema	Motta
1992	5-Jun	10-Jun	10-May	7-Jun	30-Jun	5-Jun	28-Jun	26-Jun	30-Jun	5-Jun	28-Jun
1993	22-May	14-May	17-May	11-May	14-May	22-May	14-May	20-May	13-May	20-May	14-May
1994	28-May	6-May	3-May	9-May	29-Jun	3-May	4-Jun	24-May	30-Jun	25-May	3-May
1995	27-May	29-May	28-May	17-May	28-Jun	27-May	28-Jun	27-May	12-May	27-May	26-Jun
1996	20-May	11-May	9-May	10-May	7-Jun	16-May	10-May	10-May	11-May	18-May	10-May
1997	12-May	8-May	5-May	18-May	31-May	6-May	17-May	6-May	19-Jun	18-Jun	7-May
1998	2-Jun	3-Jun	29-May	2-Jun	25-Jun	1-Jun	18-Jun	10-Jun	26-Jun	29-May	1-Jun
1999	7-May	23-Jun	6-May	28-May	28-Jun	3-May	21-Jun	24-May	29-Jun	29-May	27-Jun
2000	11-May	11-Jun	11-Jun	6-Jun	26-Jun	10-May	10-Jun	28-May	30-Jun	12-May	28-Jun
2001	18-May	9-Jun	18-May	16-May	28-May	17-May	11-May	24-May	12-May	17-May	13-May
2002	28-May	5-Jun	2-Jun	5-Jun	30-Jun	30-May	14-Jun	28-May	22-Jun	31-May	21-Jun
2003	14-Jun	14-Jun	28-May	15-Jun	25-Jun	1-Jun	26-Jun	11-Jun	27-Jun	31-May	22-Jun
2004	5-Jun	21-Jun	1-Jun	6-Jun	24-Jun	9-Jun	12-Jun	11-Jun	18-Jun	5-Jun	18-Jun
2005	25-May	19-Jun	24-May	18-Jun	26-Jun	3-Jun	20-Jun	12-Jun	28-Jun	25-May	13-Jun
2006	6-May	4-May	11-May	4-Jun	30-Jun	8-May	4-May	18-May	30-Jun	12-May	5-May
2007	6-May	4-Jun	20-May	9-May	15-Jun	21-May	4-Jun	27-May	17-Jun	5-Jun	18-Jun
2008	4-May	4-May	4-May	3-May	3-May	3-May	3-May	5-May	6-Jun	16-May	3-May
2009	3-Jun	21-Jun	26-May	16-Jun	29-Jun	4-Jun	27-Jun	6-Jun	29-Jun	26-May	30-Jun
2010	23-May	15-Jun	27-May	4-May	4-May	26-May	5-Jun	11-Jun	30-Jun	27-May	30-Jun
2011	11-May	25-May	11-May	16-May	16-May	11-May	17-May	14-Jun	17-May	11-Jun	17-May
2012	8-May	19-Jun	11-May	22-Jun	22-Jun	17-May	22-Jun	21-Jun	22-Jun	15-May	20-Jun
2013	13-Jun	30-Jun	13-May	13-May	15-Jun	13-May	20-Jun	25-May	15-Jun	1-Jun	13-May
2014	9-May	9-Jun	7-May	4-May	11-May	10-May	7-May	10-May	10-May	9-May	9-May
2015	5-May	15-Jun	5-May	5-May	29-Jun	7-May	27-May	6-May	28-Jun	9-May	5-May

ID. STN	Aykel	Bahir Dar	Chagni	Debre Mark	Debre Wor	Dangila	Debre Tabo	Gonder	Nfas Mewuc	Metema	Motta
2016	3-May	18-Jun	6-May	3-May	3-May	4-May	29-May	17-Jun	3-May	30-Jun	26-Jun
2017	15-May	8-May	8-May	6-May	29-Jun	8-May	7-May	13-May	14-May	19-May	7-May
2018	8-May	20-May	10-May	20-May	18-May	23-May	30-May	26-May	3-Jun	12-Jun	26-Jun
2019	12-May	24-May	23-May	22-May	8-Jun	27-May	29-May	28-May	19-May	24-May	30-May
2020	17-May	17-May	10-May	8-May	8-May	8-May	16-May	18-May	30-Jun	7-Jun	4-Jun
2021	4-May	22-Jun	4-Jun	4-Jun	30-Jun	3-May	21-Jun	4-May	30-Jun	8-Jun	19-Jun
Average	18-May	2-Jun	16-May	21-May	10-Jun	17-May	2-Jun	27-May	11-Jun	27-May	3-Jun

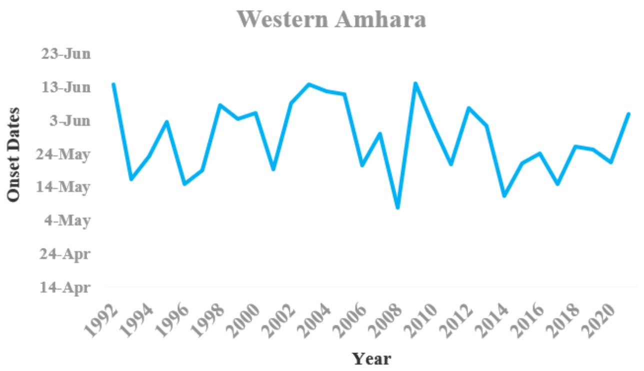


Figure 3. *Areal mean onset Date of rainfall for western Amhara, Ethiopia.*

3.2. Rainfall Cessation

In this study, the end date of rainfall of Bahir Dar, Motta, Debre Markos, and Dangla Was 271, 269,271, and 261 respectively. However [13] the end of the rainy season of Bahir Dar, Motta, Debre Markos, and Dangla was; 302, 304, 302, and 317 DOY, respectively. Similarly, the mean cessation date of western Amhara ranged from Sep 13 to oct-13. While Dereje *et al*. (2012) reported the average date of end of rainfall in Amhara region ranged from (September 22) to (October 30). The early and late cessation dates of the western Amhara Ethiopia are July 14 and October 15, respectively.

The end of the *Kiremt* season was more extended and shortened at Chagni and Metema compared to other areas. This study concludes that the mean Cessation Date of western Amhara is Sep 29. The stability of the cessation Date of rainfall for western Amhara, Ethiopia is very highly stable (SD= 4) if one standard deviation of the mean it means that 68% of the Cessation date of the rainfall fall between September 25 to October 3. If 2 standard deviations of the mean it means that 95% of the Cessation date of the rainfall fall between September 21 to October 7. See Table 4 the cessation date of the rainfall in western Amhara study meteorological station and Figure 25(a-k) in the appendix presents the rainfall cessation of each station over western Amhara.

The cessation of the *Kiremt* (long) rainy season in the western Amhara region of Ethiopia typically occurs around September. However, similar to the onset of the rainy season, the exact timing of rainfall cessation can vary slightly from year to year and within different parts of the region.

In the western Amhara region, including areas such as Bahir Dar, Gondar, and surrounding districts, the *Kiremt* rains gradually taper off towards the end of September. By this time, rainfall becomes less frequent and intense, marking the transition to the dry season.

The cessation of the *Kiremt* rains is an essential indicator for farmers in the region as it signifies the end of the main growing season. It allows farmers to plan for harvesting, post-harvest activities, and preparations for the dry season.

The timing of rainfall cessation in the western Amhara region, as in other parts of Ethiopia, is influenced by various factors, including atmospheric conditions, the movement of weather systems, and regional climate patterns. Climate variability and change may also impact the duration and intensity of the rainy season, leading to variations in the timing of rainfall cessation from year to year.

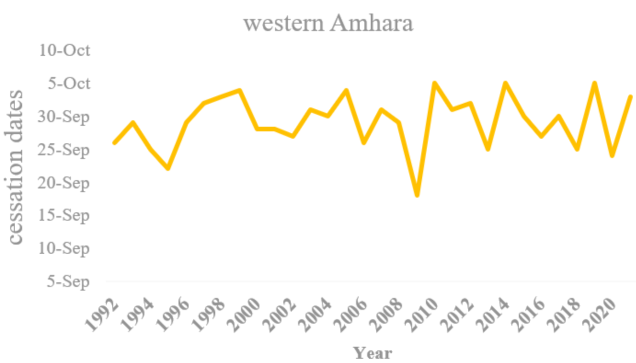


Figure 4. *Areal mean Cessation Date of rainfall for western Amhara, Ethiopia.*

Table 4. *Cessation date of the rainfall in western Amhara study meteorology station.*

ID. STN	Aykel	Bahir Dar	Chagni	Debre Markos	Debre Work	Dangil a	Debre Tabor	Gonder	Nefas Mewucha	Metema	Motta
1992	15-Sep	15-Oct	15-Oct	28-Sep	17-Sep	30-Sep	28-Sep	16-Sep	15-Sep	28-Sep	28-Sep
1993	15-Oct	15-Sep	15-Oct	15-Oct	19-Sep	14-Oct	19-Sep	20-Sep	20-Sep	11-Oct	16-Sep
1994	2-Oct	2-Oct	1-Oct	2-Oct	15-Sep	1-Oct	2-Oct	17-Sep	29-Sep	15-Sep	15-Sep
1995	17-Sep	22-Sep	15-Oct	27-Sep	15-Sep	27-Sep	26-Sep	15-Sep	25-Sep	15-Sep	15-Sep
1996	23-Sep	23-Sep	15-Oct	11-Oct	15-Sep	15-Oct	22-Sep	19-Sep	21-Sep	23-Sep	15-Oct
1997	20-Sep	9-Oct	15-Oct	25-Sep	1-Oct	25-Sep	7-Oct	15-Oct	27-Sep	23-Sep	6-Oct
1998	3-Oct	26-Sep	15-Oct	15-Oct	15-Sep	15-Oct	2-Oct	15-Sep	26-Sep	6-Oct	15-Oct
1999	3-Oct	1-Oct	15-Oct	29-Sep	15-Sep	15-Oct	15-Oct	22-Sep	28-Sep	15-Oct	15-Oct
2000	15-Oct	23-Sep	15-Oct	15-Oct	16-Sep	15-Oct	23-Sep	16-Sep	21-Sep	17-Sep	15-Sep
2001	15-Oct	2-Oct	15-Oct	22-Sep	23-Sep	1-Oct	6-Oct	15-Sep	22-Sep	20-Sep	24-Sep
2002	20-Sep	26-Sep	15-Oct	5-Oct	15-Sep	6-Oct	29-Sep	15-Sep	19-Sep	24-Sep	3-Oct
2003	10-Oct	13-Oct	14-Oct	8-Oct	15-Sep	8-Oct	8-Oct	22-Sep	18-Sep	15-Sep	10-Oct
2004	7-Oct	4-Oct	15-Oct	28-Sep	15-Sep	15-Oct	28-Sep	1-Oct	15-Sep	2-Oct	28-Sep
2005	16-Sep	15-Oct	15-Oct	15-Oct	16-Sep	15-Oct	6-Oct	1-Oct	16-Sep	8-Oct	15-Oct
2006	28-Sep	25-Sep	15-Oct	6-Oct	21-Sep	15-Oct	23-Sep	16-Sep	22-Sep	20-Sep	15-Sep
2007	29-Sep	28-Sep	15-Oct	11-Oct	14-Oct	29-Sep	29-Sep	22-Sep	23-Sep	11-Oct	17-Sep
2008	24-Sep	27-Sep	15-Oct	7-Oct	21-Sep	27-Sep	29-Sep	18-Sep	15-Sep	14-Oct	10-Oct
2009	7-Oct	17-Sep	21-Sep	15-Sep	15-Sep	15-Sep	18-Sep	15-Sep	15-Sep	15-Sep	15-Sep
2010	28-Sep	15-Oct	15-Oct	10-Oct	27-Sep	15-Oct	2-Oct	16-Sep	27-Sep	6-Oct	15-Oct
2011	15-Oct	27-Sep	15-Oct	7-Oct	19-Sep	6-Oct	27-Sep	21-Sep	26-Sep	26-Sep	6-Oct
2012	10-Oct	7-Oct	12-Oct	4-Oct	3-Oct	25-Sep	8-Oct	4-Oct	28-Sep	27-Sep	17-Sep
2013	28-Sep	23-Sep	15-Oct	28-Sep	22-Sep	15-Oct	19-Sep	15-Sep	20-Sep	15-Sep	19-Sep
2014	26-Sep	15-Oct	15-Oct	15-Oct	17-Sep	15-Oct	26-Sep	23-Sep	27-Sep	15-Oct	15-Oct
2015	20-Sep	21-Sep	15-Oct	2-Oct	25-Sep	10-Oct	25-Sep	19-Sep	10-Oct	4-Oct	9-Oct
2016	15-Sep	8-Oct	15-Oct	10-Oct	15-Sep	7-Oct	6-Oct	16-Sep	23-Sep	22-Sep	15-Sep
2017	29-Sep	1-Oct	15-Oct	10-Oct	28-Sep	5-Oct	17-Sep	18-Sep	17-Sep	25-Sep	15-Oct
2018	22-Sep	24-Sep	15-Oct	24-Sep	26-Sep	28-Sep	21-Sep	21-Sep	20-Sep	1-Oct	15-Sep
2019	23-Sep	29-Sep	15-Oct	11-Oct	11-Oct	11-Oct	15-Oct	26-Sep	26-Sep	15-Oct	26-Sep
2020	20-Sep	12-Oct	15-Oct	10-Oct	22-Sep	11-Oct	26-Sep	20-Sep	22-Sep	926	13-Oct
2021	2-Oct	15-Oct	15-Oct	15-Oct	2-Oct	15-Oct	2-Oct	16-Sep	26-Sep	22-Sep	28-Sep
Average	28-Sep	1-Oct	13-Oct	5-Oct	21-Sep	7-Oct	29-Sep	20-Sep	22-Sep	13-Sep	29-Sep

3.3. Length of Growing Period

In this study, the mean rainfall Length of growing period of Bahir Dar, Motta, Debre Markos, and Dangla was 121, 119, 129, and 142 days respectively. The range of rainfall Duration was between 103 DOY at Debre Work to 151 DOY at Changi. However [13] reported that the mean Rainfall Duration of

Bahir Dar, Motta, Debre Markos, and Dangla is 149,153, 158, and 185 days respectively. The Length of growing period of rainfall is shorter than in the previous studies conducted by [13].

This study concludes that the Mean Length of Growing period of western Amhara Ethiopia is 124 days. Dereje *et al.* (2012) reported that in some stations, the length of the growing period was <100 days; in others, it was >140 days in the studied station. The minimum and maximum length of growing period for western Amhara Ethiopia is 77 and 165 respectively.

The result implication shows that early rainfall onset coincided with a late rainfall cessation date, resulting in a longer length of growing period than the mean. And if the late rainfall onset coincided with the early rainfall cessation date, resulting in a shortened length of growing period, then the mean as in the case of western Amhara, Ethiopia. On the other hand, the late rainfall onset coincided with the late cessation, resulting in a longer length of growing period than the mean. Early rainfall onset coincided with early rainfall cessation dates, resulting in a shorter growing period than the mean. Early or late rainfall onset and cessation lead to a change in the length of the growing period. This information helps rain-fed agriculture, food, and cash crop farmers make decisions on crop varieties, where and when to plant, and harvest for sustainable food security in the western Amhara region.

The stability of length of the growing period for western Amhara, Ethiopia is highly stable (SD=13). If one standard deviation of the mean it means that 68% of the Length of growing periods falls between 110 to 136 days. If 2 standard deviations of the mean it means that 95% of the Length of growing period of the rainfall falls between 97 to 149 days. See Table 5 the length of growing period of the rainfall in western Amhara study meteorological station and Figure 26(a-k) in the appendix presents the Length of growing period of each station over western Amhara.

The length of the growing period for crops in the western Amhara region of Ethiopia varies depending on several factors, including the type of crop, local climatic conditions, and agricultural practices.

For staple crops such as maize, teff, sorghum, and millet, the growing period in the western Amhara region typically ranges from about three to six months. Here's a general breakdown of the growing periods for some common crops in the region:

Understanding the length of the growing period is essential for farmers to effectively plan their planting and harvesting schedules, optimize crop yields, and ensure food security for their households and communities in the western Amhara region of Ethiopia.

Generally, the main problem in Western Amhara was the duration of rainfall and the fluctuation of the onset and cessation dates of rainfall relative to the previous year.

Table 5. *Length of growing period of the rainfall in western Amhara study meteorology station.*

Year	Aykel	Bahir Dar	Chagni	Debre Mark	Debre Work	Dangila	Debre Tabor	Gonder	Nefas Mewuch	Motta	Metema
1992	102	127	163	113	79	117	92	82	77	92	115
1993	146	124	148	157	128	145	128	123	130	125	144
1994	127	149	152	146	78	151	120	116	91	135	113
1995	113	116	139	133	79	123	90	111	136	81	111
1996	126	135	158	154	100	152	135	132	133	158	128
1997	131	154	163	130	123	142	143	162	100	152	97
1998	123	115	138	135	82	136	106	97	92	136	130
1999	149	100	162	124	79	165	116	121	91	110	139
2000	157	104	157	131	82	158	105	111	83	79	128
2001	150	115	150	129	118	137	148	114	133	134	126
2002	115	113	135	122	77	129	107	110	89	104	116
2003	118	121	139	115	82	129	104	103	83	110	107
2004	124	105	136	114	83	128	108	112	89	102	119
2005	114	118	144	119	82	134	108	111	80	124	136
2006	145	144	157	124	83	160	142	121	84	133	131
2007	146	116	148	155	121	131	117	118	98	91	128

Year	Aykel	Bahir Dar	Chagni	Debre Mark	Debre Work	Dangila	Debre Tabor	Gonder	Nefas Mewuch	Motta	Metema
2008	143	146	164	157	141	147	149	136	101	160	151
2009	126	88	118	91	78	103	83	101	78	77	112
2010	128	122	141	159	146	142	119	97	89	107	132
2011	157	125	157	144	126	148	133	99	132	142	107
2012	155	110	154	104	103	131	108	105	98	89	135
2013	107	85	155	138	99	155	91	113	97	129	106
2014	140	128	161	164	129	158	142	136	140	159	159
2015	138	98	163	150	88	156	121	136	104	157	148
2016	135	112	162	161	135	156	130	91	143	81	84
2017	137	146	160	157	91	150	133	128	126	161	129
2018	137	127	158	127	131	128	114	118	109	81	111
2019	134	128	145	142	125	137	139	121	130	119	144
2020	126	148	158	155	137	156	133	125	84	131	111
2021	151	115	133	165	94	165	103	135	88	101	106
Average	133	121	151	137	103	142	119	116	104	119	123

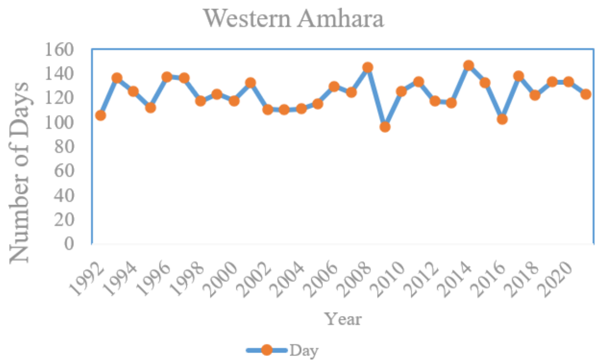


Figure 5*. Areal mean Length of growing period for western Amhara, Ethiopia.*

4. Conclusion and Recommendations

4.1. Conclusion

This study examined rainfall characterization, including onset, cessation dates, and length of the growing period (LGP), across 11 meteorological stations in Western Amhara, Ethiopia, from 1992 to 2021 using the Climate Data Tool (CDT). The results revealed that the *Kiremt* (main rainy season) rainfall onset in the region is relatively stable, with a mean onset date of May 28 (DOY ~149) and a standard deviation of 11 days, indicating high predictability for agricultural planning. The cessation date of rainfall also showed very high stability, occurring around late September (DOY ~270), which supports reliable determination of the end of the growing season. The calculated length of the growing period was generally consistent, with a mean LGP of approximately 122 days, which is adequate for most staple crops grown in the area.

These findings confirm that Western Amhara exhibits a highly predictable mono-modal rainfall regime, which is crucial for rain-fed agriculture. The results also highlight that rainfall onset and cessation dates, as well as LGP, have not shown extreme fluctuations over the last three decades, suggesting a relatively stable seasonal pattern despite global concerns about climate variability. This stability is an advantage for agricultural planning, allowing farmers to make better-informed decisions on planting schedules, crop selection, and water management.

However, spatial and temporal variations in rainfall onset and cessation across different stations underline the importance of localized climate information for farm-level decision-making. Strengthening climate monitoring networks and providing early warning systems could further enhance farmers' adaptive capacity. Policymakers and development practitioners should use such rainfall characterization studies to design climate-resilient agricultural strategies, improve food security, and build community resilience to future climate variability.

4.2. Recommendations

Based on the findings of this study, it is recommended that policymakers, agricultural extension *workers, and local* *authorities* strengthen climate information services in Western Amhara by providing timely and reliable rainfall forecasts, including onset and cessation dates, to farming communities. This will help farmers optimize planting dates, select appropriate crop varieties, and reduce the risk of yield losses associated with mistimed planting. Moreover, integrating rainfall variability analysis into local agricultural planning and water resource management strategies will improve drought preparedness and irrigation scheduling. Capacity-building programs should also be implemented to enhance farmers' adaptive skills and promote climate-smart agricultural practices, such as soil and water conservation, drought-tolerant crop adoption, and diversified farming systems. At a broader scale, expanding the network of meteorological stations and using tools like CDT for continuous monitoring will improve the accuracy of climate data, enabling better decision-making. Finally, collaboration between research institutions, government agencies, and local communities is essential to ensure that climate information is not only generated but also effectively communicated and used to build resilience against the adverse impacts of climate change in Western Amhara.

Abbreviations

AEZs	Agro-ecological Zones
ANRS	Amhara National Regional State
CDT	Climate Data Tool
GHGs	Greenhouse Gases
DOY	Day of the Year
LGP	Length of Growing Period

Author Contributions

Behabtu Gobeze Mengiste: Conceptualization, data collection, statistical analysis, and writing original draft preparation.

Temesgen Admasu Yazachew: Supervision, Writing-review & editing.

Conflicts of Interest

The author declares that there is no conflict of interest.

Appendix

An outlier of meteorological Station

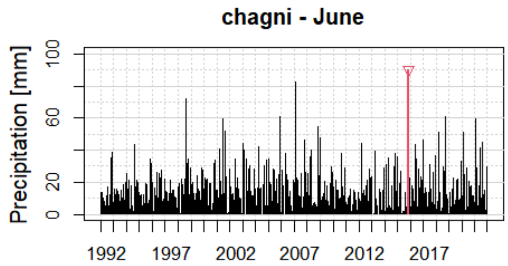


Figure 6. *Data quality check: typing error during data entry: 90.2 mm rainfall data entered in place of 9.7 mm.*

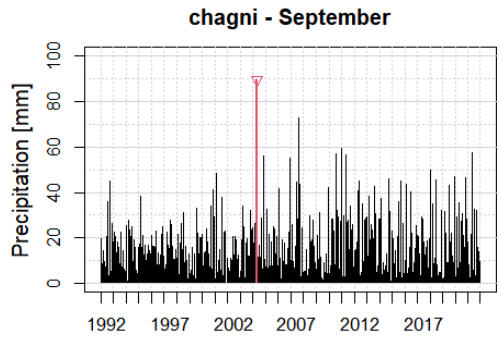


Figure 7. *Data quality check: in 2004/09/11 is recorded 89.6 is an outlier but when checked a hard copy it is 89.6 is the same so accept it.*

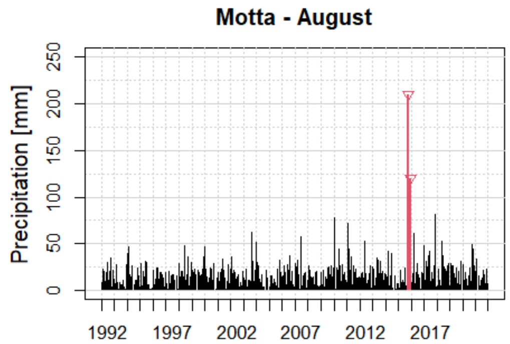


Figure 8. *Data quality check: typing error during data entry: 210 mm rainfall data entered in place of 21 mm.*

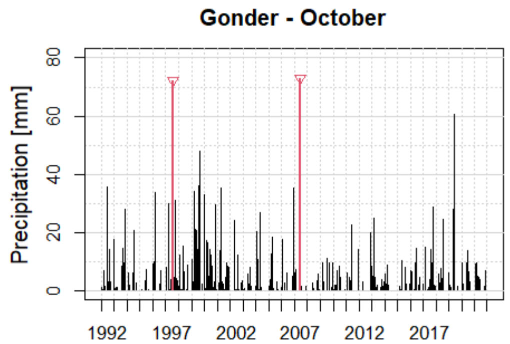


Figure 9. *Data quality check: typing error during data entry: 73 mm rainfall data entered in place of 7.3 mm. And in 1997/10/19 is an outlier but when checked a hard copy it is true so accept.*

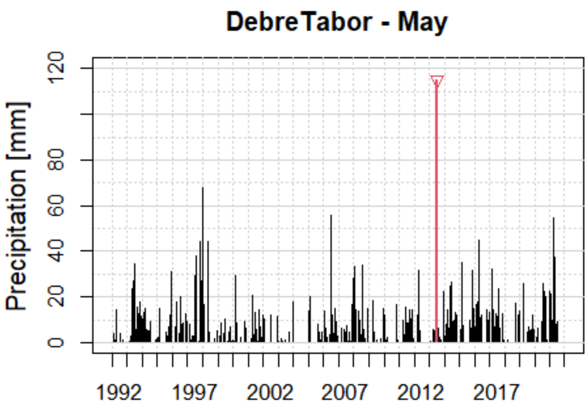


Figure 10. *Data quality check: typing error during data entry: 115 mm rainfall data entered in place of 11.5 mm.*

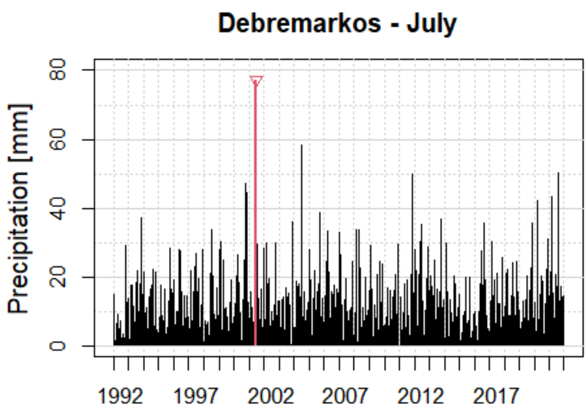


Figure 12. *Data quality check: In 2001/07/17 is recorded 77.2 as an outlier but when check a hard copy 77.2 was recorded so accept it.*

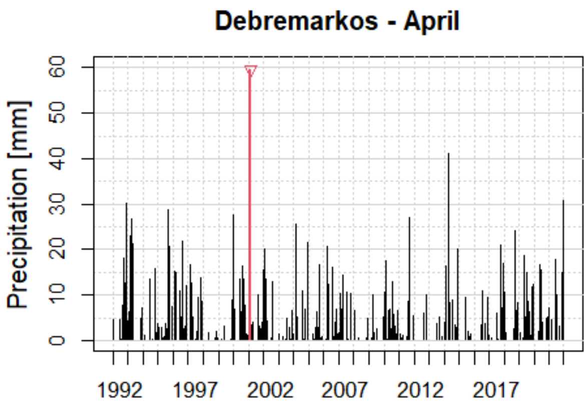


Figure 11. *Data quality check: In 2001/07/17 is recorded as 59.5 is an outlier but when checked a hard copy 59.5 was recorded so accept it.*

Monthly homogeneity test for all study station

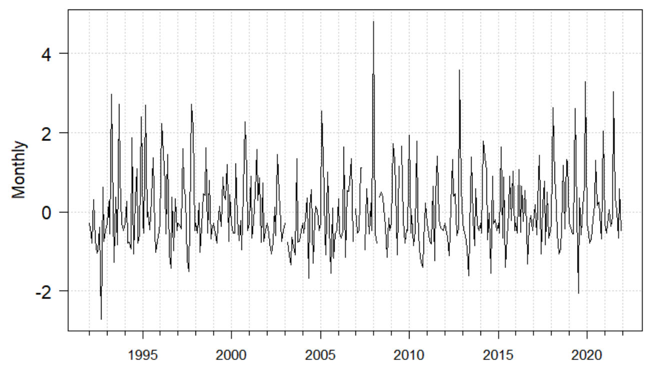


Figure 13. *Aykel monthly homogeneity test.*

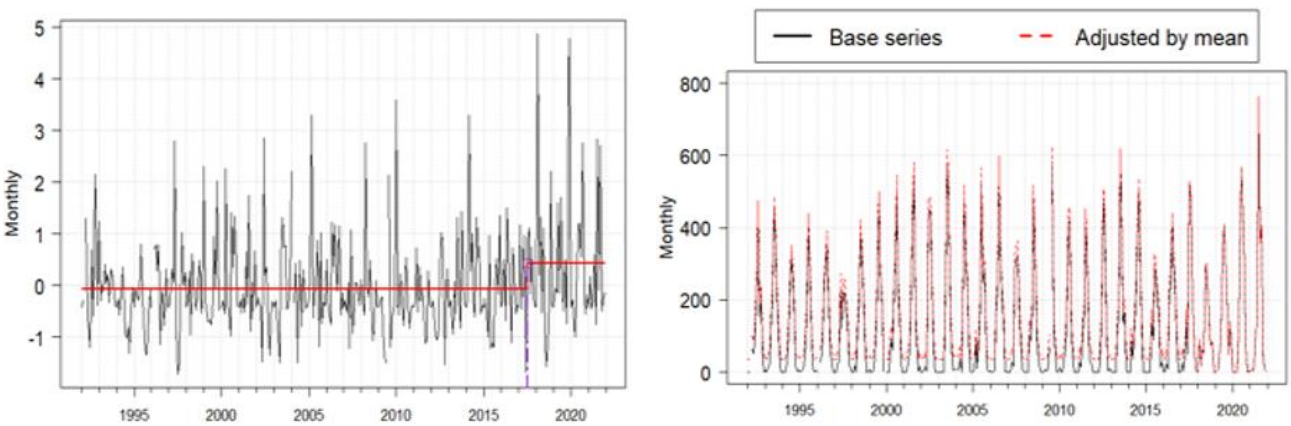


Figure 14. *Bahir Dar monthly homogeneity test.*

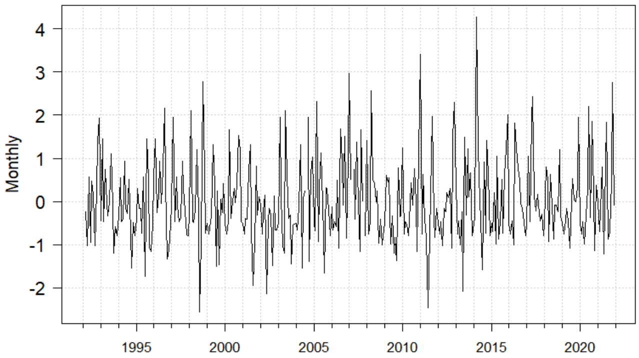


Figure 15. *Chagni monthly homogeneity test.*

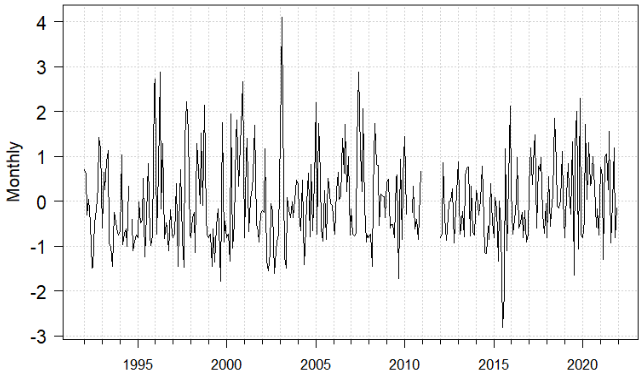


Figure 16. *Debre work monthly homogeneity test.*

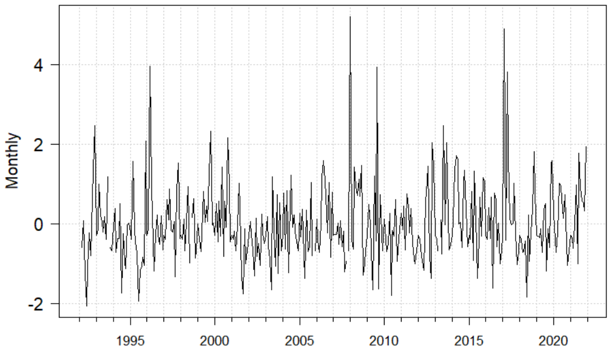
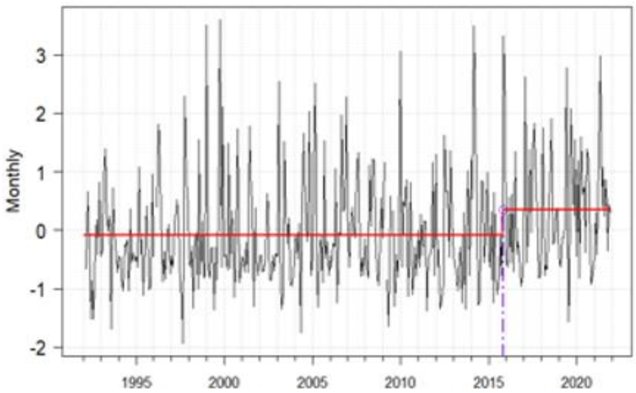


Figure 17. *Dangila monthly homogeneity test.*



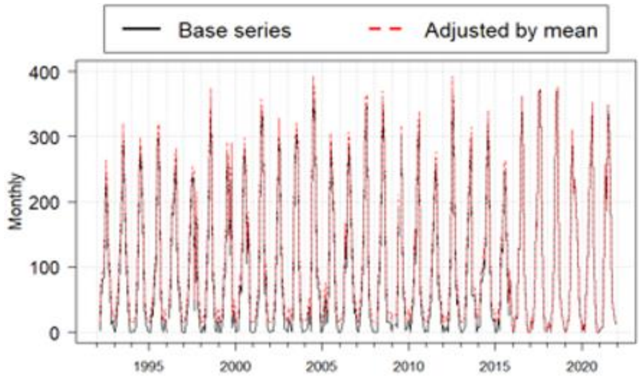


Figure 18. *Gonder monthly homogeneity test.*

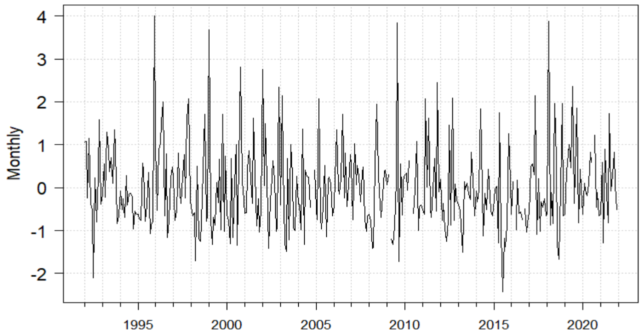
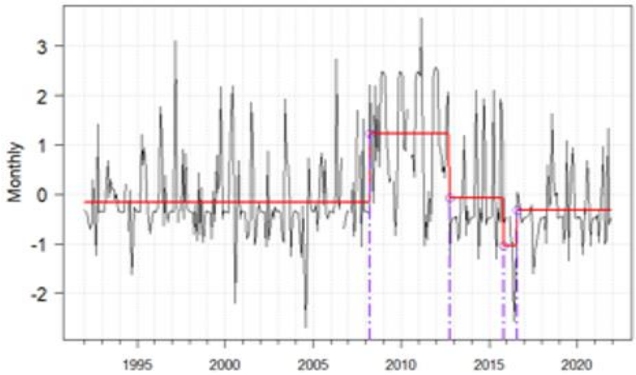


Figure 19. *Debre Markos monthly homogeneity test.*



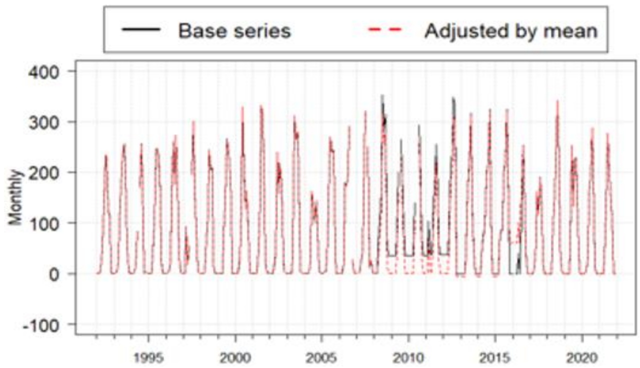


Figure 20. *Metema monthly homogeneity test.*

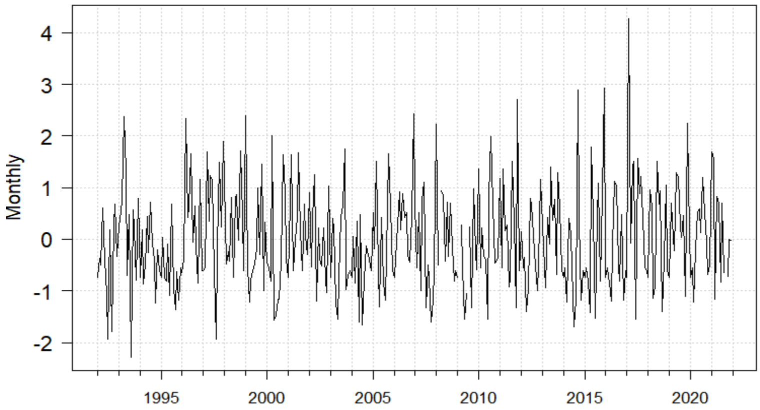


Figure 21. *Motta monthly homogeneity test.*

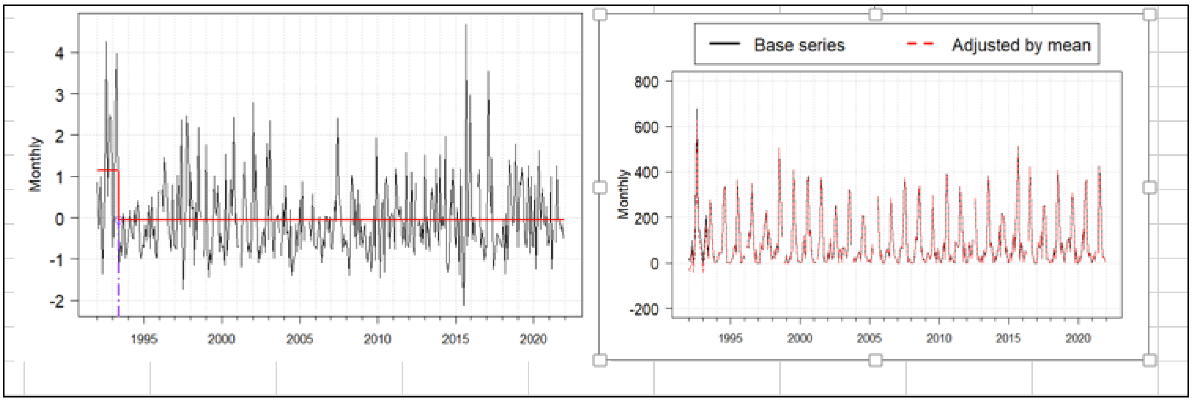


Figure 22. *Nefas mewucha monthly homogeneity test.*

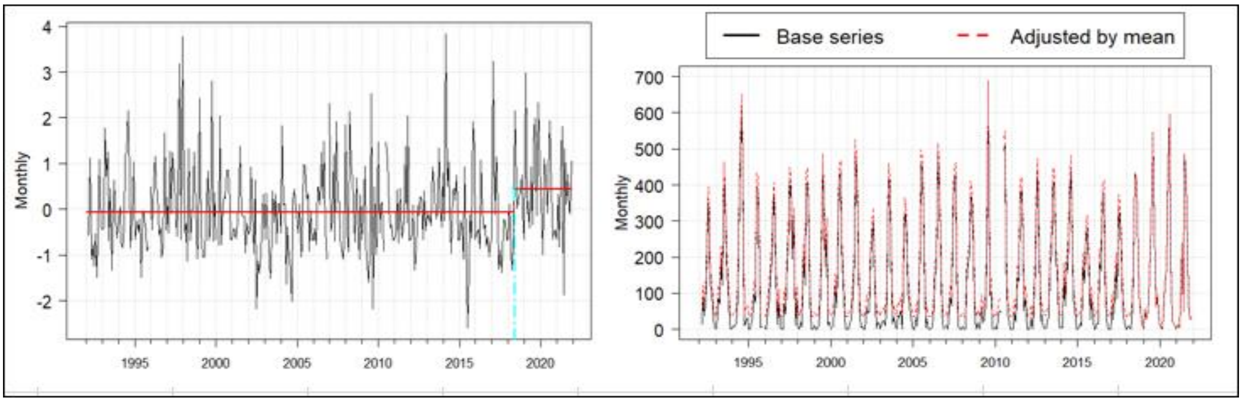


Figure 23. *Debre tabor monthly homogeneity test.*

Onset dates of all study stations in graph

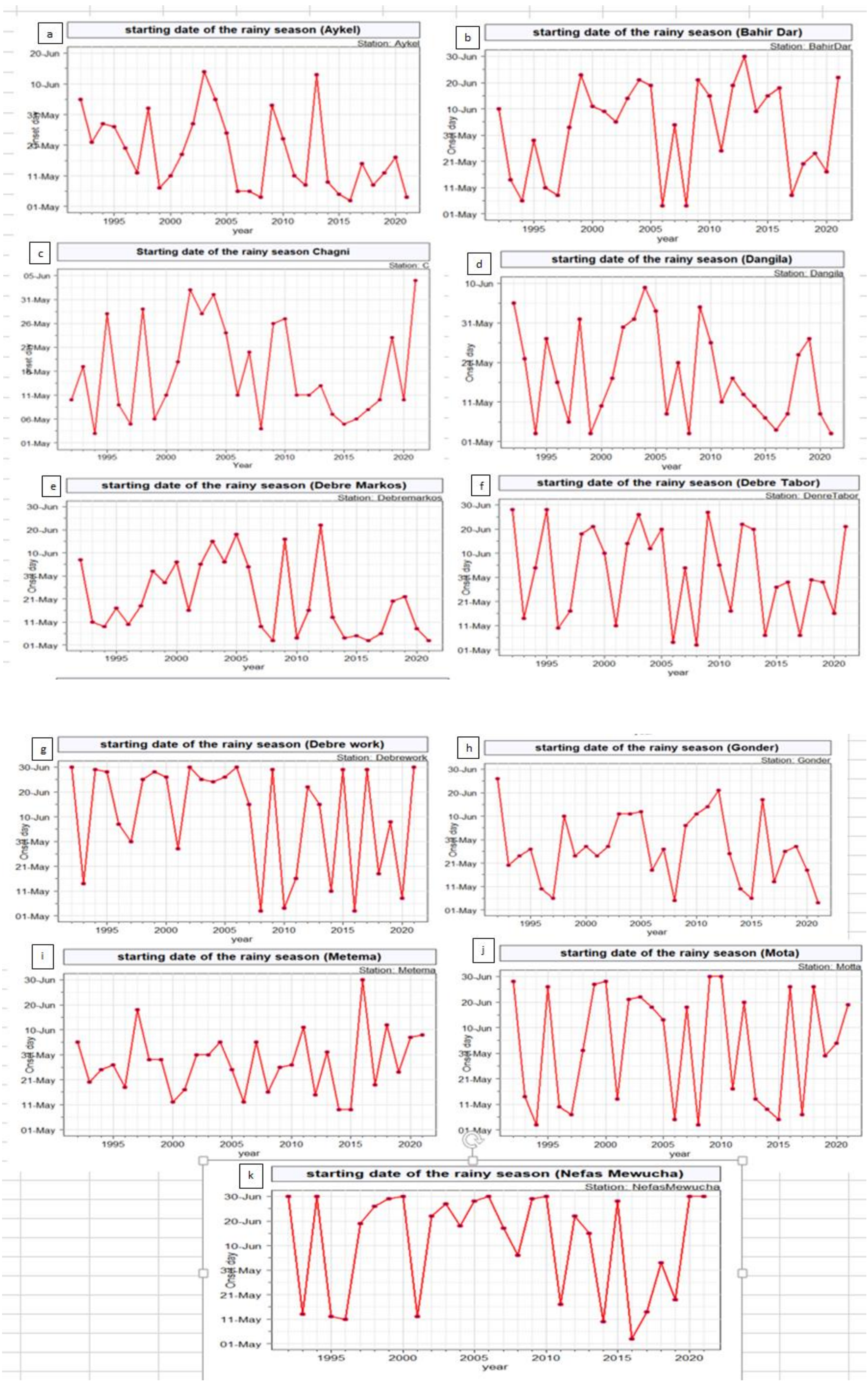


Figure 24. *onset dates of the rainy season in each station over western Amhara Ethiopia*.

Cessation dates of all the study stations in graph

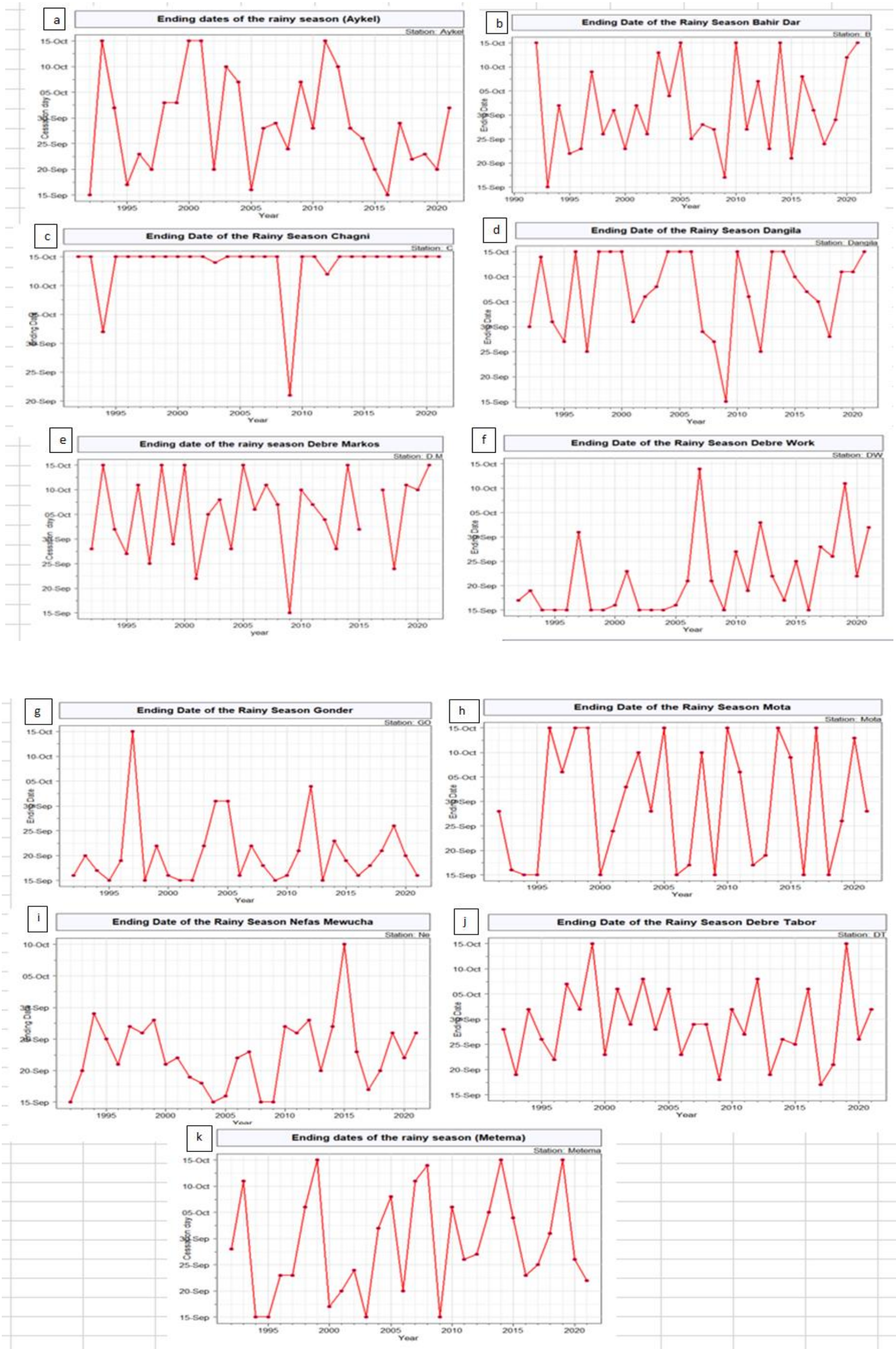
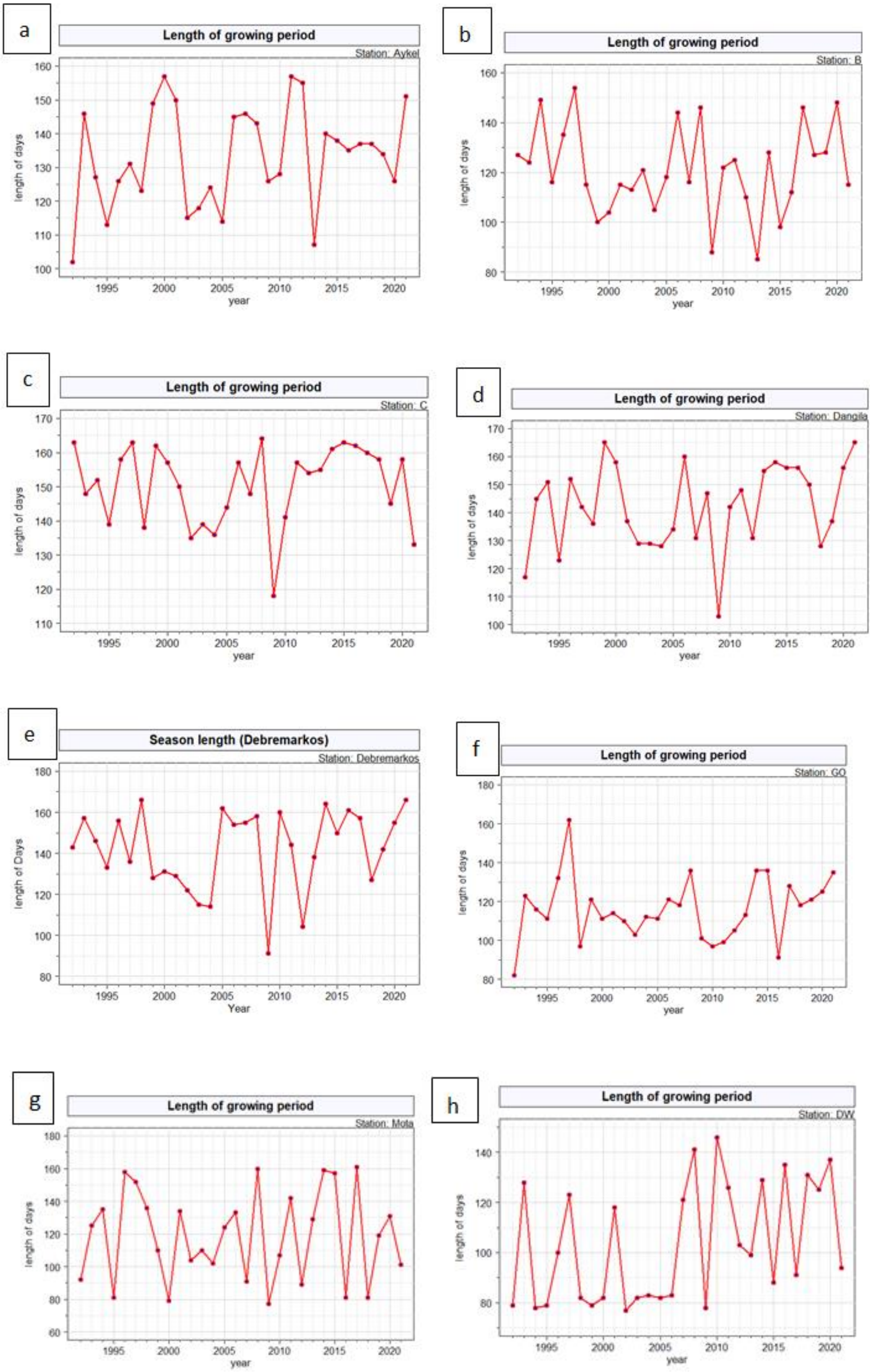


Figure 25. *Cessation date of the rainy season in each station over western Amhara Ethiopia*.


a
Length of growing period
Station: Aykel
length of days
year
b
Length of growing period
Station: B
length of days
year
c
Length of growing period
Station: C
length of days
year
d
Length of growing period
Station: Dangila
length of days
year
e
Season length (Debremarkos)
Station: Debremarkos
length of Days
Year
f
Length of growing period
Station: GO
length of days
year
g
Length of growing period
Station: Mota
length of days
year
h
Length of growing period
Station: DW
length of days
year

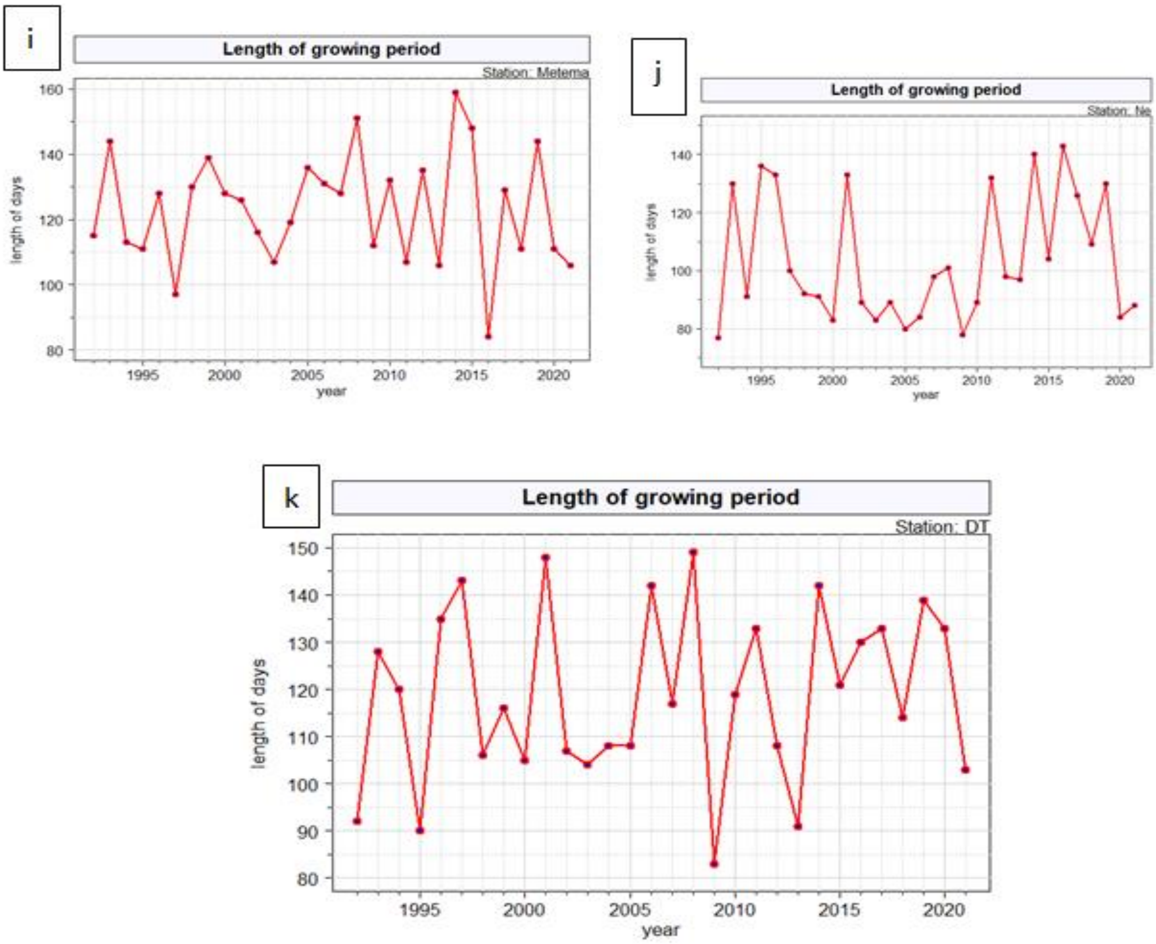


Figure 26. *Length of growing period in each station over western Amhara Ethiopia.*

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