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Research Article

Characterization of Rainfall Trends, Variability and Their Implications on Crop Growing Seasons in Eastern Amhara, Ethiopia

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Abstract

This study investigates the characterization of rainfall season trends and variability and their implications on crop growing seasons in Eastern Amhara, Ethiopia. Understanding rainfall patterns is very important for agricultural planning, water resource management, and climate resilience in a region heavily dependent on rain-fed agriculture. Different researches clearly show the influence of global climate phenomena on regional precipitation patterns and the challenges posed by climate variability in Africa, particularly in Ethiopia. This study is done using CHIRPS data based on the geographical location of 20 areas in the study area over a 40-year period (1981-2020). R Instate software is used to determine onset and cessation dates and Mann-Kendall trend analysis, Coefficient of Variability, Standardized Anomaly Index and Precipitation Concentration Index are used to see the variability and trend of rainfall, rainfall onset and cessation dates. Findings reveal a consistent rainfall onset in early June across most locations, with some areas experiencing earlier or later starts, indicating regional climatic heterogeneity. The cessation of rainfall typically occurs in mid-September, although some areas report variations. CV result shows moderate to low variability in rainfall distribution across Eastern Amhara. Mann Kendall trend analysis showed that all months except June have shown no significant trend with P values over 0.05. An increasing trend is only seen in June for the month June with a p-value of 0.004. No significant trend in onset dates observed in the study area. 5 shows increasing trend and the rest showed no trend on cessation dates. 3 out of twenty areas show significant increasing trend (Amba Mariam, Majete and Wegeltena) on LGP. The SAI, PCI and CV results show a range of results for all the areas and years. Adaptive strategies are necessary to address the identified trends and variability. Farmers are encouraged to adjust cropping calendars, adopt drought-resistant crop varieties, and invest in water harvesting and irrigation infrastructure. The recommendations include integrated water resource management approaches, including investments in rainwater harvesting, storage reservoirs, and efficient irrigation systems. Collaboration among policymakers, researchers, local communities, and development practitioners is crucial to enhance resilience to changing rainfall patterns.

Keywords

Rainfall Variability and Trends Analysis, Characterization of Rainfall, Eastern Amhara, Ethiopia

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1. Introduction

1.1. Background of the Study

Agriculture is a cornerstone of the Amhara region's economy, with rainfall patterns playing a vital role in determining the success of farming practices and the livelihoods of local communities [1]. In this area, understanding rainfall patterns is crucial due to their influence on crop yields, water availability, and food security. Rainfall patterns are a critical component of global climate dynamics, shaping ecosystems, agricultural practices, and human livelihoods worldwide [2]. Understanding changing rainfall patterns has become increasingly crucial in light of the escalating challenges posed by climate change. Across the globe, shifts in precipitation dynamics are reshaping ecosystems, economies, and human societies [3]. These alterations influence various sectors, from agriculture and water resource management to disaster preparedness and urban planning. As extreme weather events become more frequent and intense, the need for accurate predictions and adaptive strategies becomes paramount [4]. Investigating global rainfall patterns provides insights into the complex interplay between atmospheric conditions, oceanic phenomena, and manmade influences [5]. By comprehensively examining these patterns, researchers can inform global efforts to mitigate climate change impacts and enhance resilience across diverse regions.

On a global scale, rainfall variability is intricately linked to large-scale atmospheric circulation patterns, such as the El Niño-Southern Oscillation (ENSO) [6], the Indian Ocean Dipole (IOD) [7], and the North Atlantic Oscillation (NAO). These phenomena influence precipitation distribution across continents and oceans, contributing to regional climate variations. Changes in global climate systems, driven by human-induced climate change, have led to shifts in precipitation patterns [8], impacting rainfall timing and intensity in diverse regions worldwide.

In Africa, rainfall variability is a defining feature of the continent's climate, with distinct wet and dry seasons influenced by the inter-tropical convergence zone (ITCZ), monsoon systems, and other atmospheric processes [9]. The Horn of Africa, including Ethiopia, experiences complex rainfall patterns characterized by spatial and temporal variability [10]. Ethiopia situated in the northeastern part of Africa, exhibits diverse climatic zones, ranging from arid and semi-arid regions to highland areas with more abundant rainfall. The country's climate variability poses significant challenges to agricultural productivity, water resource management, and socioeconomic development.

Ethiopia's vulnerability to climate variability is further pronounced by its heavy reliance on rain-fed agriculture, which supports the livelihoods of a large portion of the population [11]. The country's agricultural sector faces recurrent challenges from droughts, floods, and erratic rainfall patterns, impacting food security and rural livelihood [12]. In response, the Ethiopian government has prioritized climate resilience and adaptation efforts, recognizing the need for scientific research to inform policy decisions and resource allocation.

Eastern Amhara is a region characterized by diverse landscapes, encompassing highlands and lowlands, each influencing its meteorological patterns [13]. One of the difficulties this region is the onset and cessation of rainfall, which plays an instrumental role in shaping the socioeconomic and environmental fabric. Agriculture, the lifeblood of the local communities, is intricately interwoven with the timing of the rainy season [14]. Understanding the dynamics of rainfall is not only imperative for successful farming practices but also crucial for sustainable water resource management and climate resilience.

Eastern Amhara has a diverse topography, which adds to the region's special meteorological environment. A series of mountains, hills, and valleys rising between 1379 and 3809 meters above sea level (masl) dominate the region's geography. The region experiences two distinct seasons of rainfall: the primary *Kiremt* (summer) season, which runs from June to September and the shorter Belg (spring) season from February to May. In light of global climate change, the localized effects on these regional weather systems become increasingly significant [15]. For the people of Eastern Amhara, the beginning and end of the rainy season has existential significance, even beyond its meteorological subtleties. Rainfall patterns, both regular and predictable, have a significant impact on water availability, agricultural output [16], and ultimately, people's quality of life. As climate change intensifies, understanding and adjusting to changing patterns of rainfall becomes critical for maintaining food security, sustainable livelihoods, and overall resilience of the region.

Despite the obvious importance of rainfall in Eastern Amhara, little is known about the particular climatic variables that control when this essential element begins and ends. Even though they offer insightful information on area climatology, existing studies sometimes lack the granularity necessary for accurate local predictions. By conducting a thorough analysis of the meteorological nuances that affect the beginning and conclusion of the rainy season in Eastern Amhara, this research is well-positioned to fill this gap. In addition to advancing our knowledge of regional climatology, the study hopes to provide useful information for resource management and sustainable agriculture. By means of this thorough investigation, we hope to contribute to the scientific understanding of regional climatology and establish a solid basis for useful interventions. By addressing important knowledge gaps, this paper hopes to increase the communities of Eastern Amhara's resilience to changing weather conditions.

1.2. Statement of the Problem

Rainfall variability challenges pose significant obstacles to various aspects of life and livelihoods in Eastern Amhara, a region situated in the northeastern part of Ethiopia. The area is characterized by diverse climatic conditions, ranging from semi-arid to humid environments, which contribute to its climate complexity. The agriculture sector which serves, the backbone of the economy, is particularly vulnerable. Unfortunately, there is a noticeable lack of knowledge regarding the start and end of the rainy season. Effective agricultural planning, water resource management, and general climate resilience in the region are severely disadvantaged by this mismatch.

Rainfall patterns play a crucial role in the local economy, with agriculture being one of the most affected sectors. Farmers in Eastern Amhara time their planting and harvesting based on the predictability of the rainy season. However, irregular or unpredictable rainfall can lead to crop failures, impacting food security and the livelihoods of farming communities. This issue extends beyond individual farms, affecting the broader socioeconomic structure of the region. As climate trends shift, historical data may no longer accurately predict rainfall patterns, making this problem increasingly urgent. Research on Ethiopia's rainfall patterns often generalizes regional climate trends, overlooking the unique rainfall characteristics of Eastern Amhara. While climate change is altering rainfall patterns globally, the specific local impacts, especially at the regional level, remain poorly understood. This study, which carefully examines the timing of rainfall in Eastern Amhara, is crucial for better planning of agricultural activities, such as planting, irrigation, and harvesting. Understanding these rainfall dynamics enhances food security in rain-fed farming areas. With more reliable information on expected rainfall, communities can better prepare for potential droughts or floods, mitigating their impact on crop production and ensuring a more stable food supply. Ultimately, adopting such practices fosters resilience among farming communities, enabling them to withstand environmental challenges and sustain their livelihoods in the long term.

1.3. Objective of the Study

1.3.1. General Objective

The general objective of this thesis is to characterize the *Kiremt* rainfall onset, cessation, and length of growing period, Assess their variability, trends and implication for crop growing season in Eastern Amhara.

1.3.2. Specific Objectives

The following are specific objectives of the study:

1. To determination of rainfall onset, rainfall cessation and LGP over the study area in the past (1981-2020);
2. To assess the variability and trend of *Kiremt* rainfall and change in the study area;
3. To analyze trends of rainfall onset, rainfall cessation and LGP in the study area.

1.4. Research Questions

What are the onsets, cessation and LGP dates in Eastern Amhara?

Is there trend and variability in the onset, cessation and LGP dates in East Amhara?

Is there a significant variability and trend in Kiremt rainfall of Eastern Amhara?

1.5. Significance of the Study

This study focuses on enhancing agricultural resilience, water resource management strategies, climate-resilient planning, and informing disaster preparedness in Eastern Amhara, Ethiopia. By analyzing rainfall patterns and trends, the research aims to maximize planting schedules, improve irrigation tactics, and reduce crop failure risks, thereby enhancing food security for farming communities. Additionally, it provides insights for efficient water resource management and sustainable solutions amidst increasing water scarcity. The study also emphasizes the importance of localized climate-resilient planning to address the unique challenges posed by climate change in Eastern Amhara. Moreover, it informs disaster preparedness by assessing anomalous rainfall events and risks associated with extreme weather, facilitating the development of early warning systems and preparedness strategies to mitigate negative impacts on communities.

2. Materials and Methods

2.1. Description of the Study Area

The study area is located in the northeastern part of Ethiopia between 8.72°N -13.25°N latitude and 38.33°E-40.29°E East and it covers area five Eastern Amhara Zones (Wag Hemira, North Wollo, South Wollo, North Shewa, and Oromia special Zone). These administrative Zones are divided into a total of 77 districts or Woreda. The area has diverse ago-climatic conditions, ranging from hot lowlands to cold highlands. The major livelihood of the people within the study Zones is a mixed crop-livestock system, in which small ruminants have a major role as cash income and as food [17, 18].

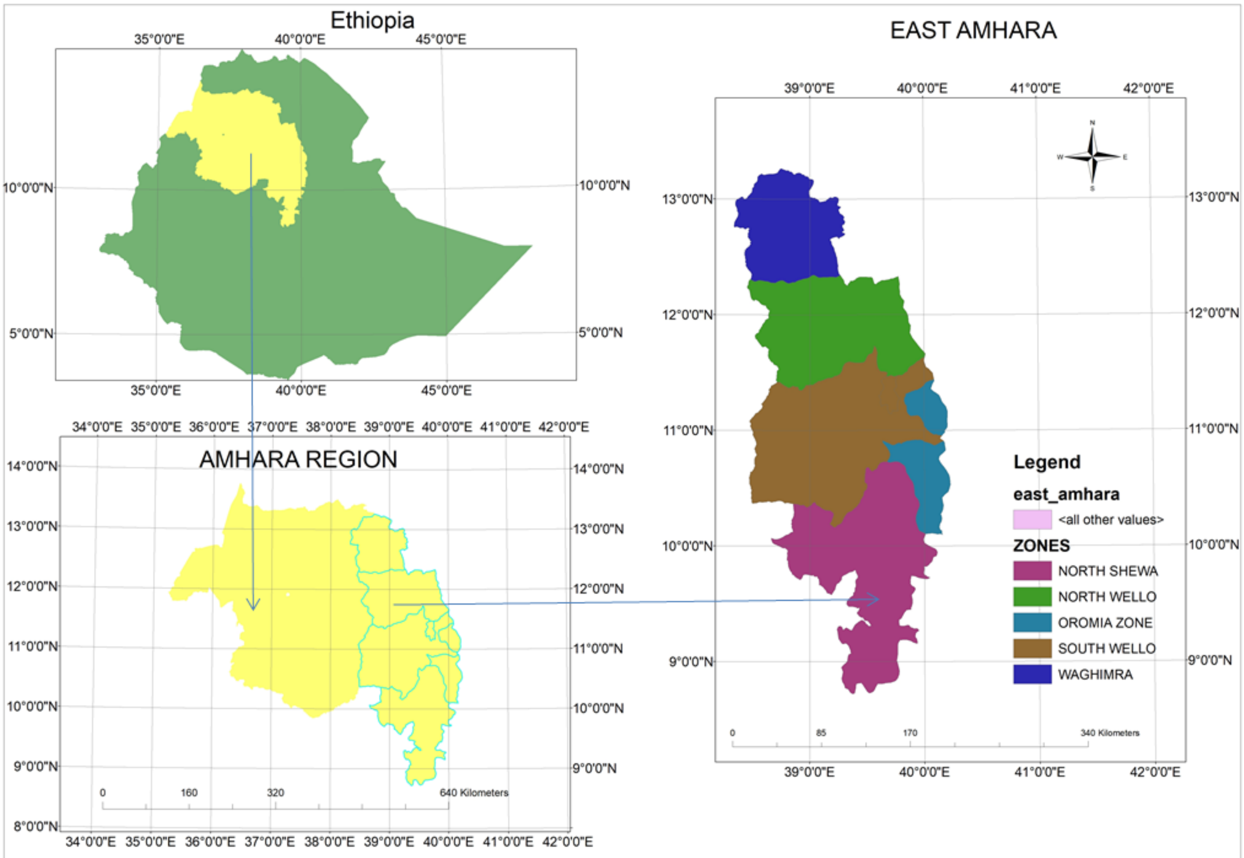

Figure 1. Map of the study area.

2.2. Climate

According to Gebrechorkos, Region has a bi-modal rainfall pattern, including the main rainy season, which is called *Kiremt* (summer) season extends from June to September, and short rainy season, which is called *Belg* (spring) from February to May. Average annual rainfalls are ranging between 516.9mm to 1342mm in the study sites [19]. At the seasonal scale, it receives 400mm-1035mm, 26mm-327mm, and 8mm-136mm in *Kiremt*, *Belg* and *Bega* seasons, respectively.

2.3. Sampling Techniques

To capture the diverse climatic conditions of East Amhara, all 20 meteorological stations in the study area were used to refine CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) grid data. This approach ensured comprehensive coverage, accurately representing regional variability in rainfall patterns. By leveraging the geographic distribution of the stations, the CHIRPS data was adjusted to align with the area's topographical and climatic diversity, providing a precise and representative analysis crucial for understanding local climate dynamics and supporting agricultural planning.

Table 1. List of Meteorological stations/ areas.

No	Area	Lat	Long
1	Alem Ketema	10.11	39.03
2	Amba Mariam	11.12	39.13
3	Amidework	12.32	38.54
4	Bati	11.083	40.017
5	Cheffa	11.3	39.86
6	Debre Birhane	9.73	39.61
7	Eneway	9.9	39.15
8	Gundomeskel	10.23	39
9	Kobo	10.13	39.63
10	Kombolcha	11	39.783
11	Lalibela	11.883	38.983
12	Majete	10.418	39.837
13	Mehal Meda	10.35	39.59
14	Mekane selam	10.7	38.8
15	Shewarobit	10	39.53

No	Area	Lat	Long
16	Shola Gebeya	9.16	39.6
17	Sirinka	11.62	39.34
18	Tsitsiqa	12.47	38.48
19	Wegeltena	11.47	39.15
20	Wereilu	10.483	39.283

2.4. Data Source

Data required for this study is daily rainfall data for the 40 years from 1981 to 2020 and is collected from high resolution grid data of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) database based on the geographical location of Meteorological stations or areas listed above in the study area and it has been accessed from the online repository https://climexp.knmi.nl/get_index.cgi. These dataset serve as the foundational elements for the subsequent analysis, providing crucial insights into the temporal patterns of rainfall variations. The CHIRPS data, which offers high-resolution precipitation estimates, is particularly valuable for understanding the distribution and intensity of rainfall events over time. CHIRPS is chosen because CHIRPS rainfall product has a strong performance in presenting daily and seasonal rainfall values over Ethiopia and can be used in developing the grid-based drought monitoring tools for the study area that could help in developing early warning systems [20].

Various articles proved the good performance of CHIRPS, For example [21] conducted a study to test it capability in the case of Ethiopia in particular by comparing the precipitation data obtained from this system with precipitation data recorded in different meteorological stations of the country. From the analysis undertaken in this study, it was established that there was high degree of accuracy noted regarding CHIRPS data with relation to the station data in areas with the numerous ground stations. This relationship was also observed when we compared CHIRPS with the seasonal and annual average rainfall in Ethiopia and therefore showed that CHIRPS can be effectively used to approximate rainfall.

Gudoshava, is yet another revealing study in which the authors have evaluated the reliability and aptitude of the CHIRPS datasets in the upper Blue Nile Basin of Ethiopia, which is a vital water source [22]. The authors highlighted that the data in the CHIRPS method were highly correlated with the actual measurements data, where the correlation coefficients ranged from 0.75 to 0.95 during different seasons. These high correlations suggest that the CHIRPS product can be used to supplement ground-based measurements, particularly in regions where well-installed ground stations are lacking.

Additionally, Malik conducted a comprehensive analysis of CHIRPS data and highlighted its reliability in capturing rainfall extremes, which are crucial for drought and flood monitoring [23]. Their findings reinforced the reliability of CHIRPS, showing strong agreement with the gauged data across various time scales. The study highlighted that CHIRPS could be instrumental in improving hydrological modeling and water resource management in the region. Gadedjisso also revealed similar results in his research that evaluates different satellite based rainfall products based on daily rainfall data. It shows CHIRPS is the best performing and is more representative of the gauged station data [24].

2.5. Determining Onset Dates

The data was analyzed using the Hargreaves method in R Instat software, which determines rainfall onset by identifying the first period meeting specific criteria: at least 1mm of rainfall per day over 5 consecutive days, with no prolonged dry spell (7 days) following [25]. The software scans the daily rainfall data to ensure these conditions are met, marking the onset date accordingly.

This study combines multiple thresholds, including rainy days, accumulated rainfall (20mm over 5 days), and wet/dry spell lengths, for more accurate onset and cessation determination. This approach addresses limitations in existing methods, providing a comprehensive analysis of rainfall patterns while accounting for variability and trends.

2.6. Determining Cessation Dates

R-Instat software was used to determine the cessation date of the rainy season, crucial for agricultural planning and water resource management. Daily rainfall data was organized in a time series, and a dry spell threshold of 10 consecutive days with less than 5mm of rainfall per day was applied. The software identified the last significant rainfall event before this dry spell, marking the cessation date accordingly.

This method ensured accurate identification of the rainy season's end, reflecting climatic patterns. R-Instat's reporting and visualization tools made the results accessible, supporting informed decision-making for agricultural and water resource management.

2.7. Calculating Length of Growing Period

Once the onset and cessation dates of the rainy season have been determined, the length of the crop growing period can be calculated. The growing period is defined as the number of days between the onset and cessation dates. This period is critical for planning agricultural activities, as it indicates the time frame within which crops can be planted, grown, and harvested. The length of the growing period directly affects crop selection, planting schedules, and irrigation planning. LGP as the number of days when soil moisture and temperature permit crop growth [26], Following this definition, LGP can be obtained by calculating the number of days between the commencement and conclusion of the rainy season.

2.8. Methods of Data Analysis

To achieve the first objective of this thesis, I employed the Mann-Kendall trend analysis to assess the trends in Kiremt rainfall over the study period. This non-parametric statistical test is widely used to identify and evaluate monotonic trends in time-series data, making it particularly suitable for analyzing climatic variables such as rainfall. By applying the Mann-Kendall method to the daily rainfall data from the CHIRPS database to determine whether there were significant increasing or decreasing trends in Kiremt rainfall over the years. This analysis will help to the long-term rainfall patterns in the East Amhara region, highlighting potential changes that could impact agricultural practices and water resource management. The results of the Mann-Kendall trend analysis thus form a critical component of the thesis, contributing to a deeper understanding of climatic trends in the context of regional agricultural sustainability.

2.9. Mann-Kendall Test

The MK test is used to perceive statistically significant decreasing or increasing trends in long-term temporal data [23]. The MK trend test is based on two hypotheses: one is null (H0) and the other is the alternative (H1) hypothesis [24]. The H0 expresses the existence of no trend while H1 elucidates a significant rising or declining trend in precipitation data [25]. On the basis of 5% significance level, if *p*-value is <0.05, then the alternative hypothesis is accepted which signifies the presence of a trend in the data and if the *p*-value is >0.05, the H0 is be accepted that denotes the absence of a trend in the data. The formula is provided by the following equation:

$$\sum_{i=1}^{mn-1} \sum_{j=i+1}^{n} \operatorname{sgn}(Xj - Xi) \quad (1)$$

Where S is the Mann-Kendal's test statistics; Xi and Xj are the sequential data values of the time series in the years i and j (j > i) and N is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series.

On the other hand sgn is given as:

$$Sgn(X_j - X_i) = \begin{cases} -1 \;\; for(Xj - Xi) < 0 \\ \;\; 0 \;\; for(Xj - Xi) = 0 \\ +1 \;\; for(Xj - Xi) > 0 \end{cases} \quad (2)$$

2.10. Standardized Anomaly Index SIA

To address objective one of assessing trend in *Kiremt* rainfall. Standardized Anomaly Index of rainfall has been calculated to examine the nature of the trends [27]. It enables the determination of the dry and wet years in the record and is used to assess frequency and severity of droughts and it is computed as:

$$SAI = \frac{X_i - \bar{X}}{\delta} \quad (3)$$

Where X_i is the annual rainfall of the particular year; $\bar{X}$ is the long-term mean annual rainfall over a period of observation and is the standard deviation of annual rainfall over the period of observation. Negative values indicate a drought period as compared to the chosen reference period while the positive ones indicate a wet situation. SAI value classification is as follows:

Table 2. Categories of the SAI value.

SAI value	Category
Above 2	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 or less	Extremely dry

The methodologies to be used for assessing the objectives of the thesis, onset dates of rainfall, cessation dates of rainfall and the length of growing period, by using the daily rainfall data are discussed below.

2.11. Coefficient of Variability (CV)

CV is used to define the variability of rainfall and to classify the degree of variability in different scales (less, moderate and high).

Less is when CV < 20%, Moderate is when CV from 20% to 30%, and High is when CV > 30%.

Areas with CV > 30% are said to be vulnerable to drought. The value of CV is computed as follows [28]:

$$CV = \frac{\delta}{\bar{X}} * 100 \quad (4)$$

Where, $\bar{x}$ and σ are the mean and standard deviation of rainfall, respectively over the given period. On the other hand σ can be computed as:

$$\sigma = \sqrt{\left[\sum_{i=1}^{n} \frac{(Xi - X)2}{n}\right]} \quad (5)$$

2.12. Precipitation Concentration Index (PCI)

Precipitation is a crucial climatic factor due to its fluctuations in intensity and quantity, which influence the occurrence of hazards like floods and droughts. This analysis is done to do more detailed analysis on objective one to understand hydrological extremes in *Kiremt* rainfall. The PCI enables quantifying the relative distribution of precipitation patterns. It also offers a good representation of the spatial variability in monthly precipitation [26] and provides insights into long-term fluctuations in the total precipitation amount [29]. The PCI can be utilized as an indicator for assessing the risks of hydrological hazards, such as floods and droughts. Precipitation Concentration Index (PCI) defines the uniformity or no uniformity of rainfall over a period (year, season, and month). The Higher the value of PCI, the greater is the no uniformity of rainfall, PCI<10 indicates uniform distribution of rainfall, values between 11 and 15 represents moderate rainfall concentration, 16<PCI<20 signifies high rainfall concentration and PCI>21 represents very high concentration [30, 31].

PCI value is determined as:

$$PCI = \frac{(\sum_{i=1}^{12} P^2)}{P^2} * 100 \quad (6)$$

Where,

p = precipitation of *i*-th month and P is the annual precipitation.

3. Results and Discussion

3.1. Onset Dates

In the analysis of rainfall onset dates across Easter Amhara, it was observed that the onset dates varied significantly, ranging from mid-May to mid-June. Areas with the earliest onset dates include Majete (13-May), Kombolcha (16-May), Lalibela (20-May), Kobo (24-May), Sirinka (24-May), and Tsitsiqa (31-May). These areas experienced the onset of rainfall earlier compared to others, indicating an earlier start of the rainy season in these areas. Conversely, areas with the latest onset dates were Bati (13-Jun), Cheffa (11-Jun), Shola Gebeya (11-Jun), Shewarobit (10-Jun), Wegeltena (10-Jun), Alem Ketema (8-Jun), Amba Mariam (8-Jun), Amidework (7-Jun), Debre Birhane (7-Jun), Enewari (7-Jun), Mehal Meda (7-Jun), and Mekane Selam (7-Jun). These findings suggest that the onset of rainfall occurred later in these regions. The variation in onset dates across the region highlights the spatial variability of the rainfall patterns within the study area, which is crucial for agricultural planning and water resource management. Onset dates are calculated over the forty years period and summary is given in the table below.

Table 3. *Onset dates for each area.*

Areas	Onset date	Areas	Onset date
Alem Ketema	8-Jun	Lalibela	20-May
Amba Mariam	8-Jun	Majete	13-May
Amidework	7-Jun	Mehal Meda	7-Jun
Bati	13-Jun	Mekane Selam	7-Jun
Cheffa	11-Jun	Shewarobit	10-Jun
Debre Birhane	7-Jun	Shola Gebeya	11-Jun
Enewari	7-Jun	Sirinka	24-May
Gundomeskel	2-Jun	Tsitsiqa	31-May
Kobo	24-May	Wegeltena	10-Jun
Kombolcha	16-May	Wereilu	9-Jun

3.2. Cessation Dates

It was observed that the cessation dates showed considerable variation, ranging from late August to mid-September. Areas with the earliest cessation dates include Wegeltena (27-Aug), Tsitsiqa (31-Aug), Wereilu (4-Sep), Kobo (10-Sep), Bati (11-Sep), Cheffa (11-Sep), Debre Birhane (11-Sep), and Lalibela (12-Sep). These areas experienced the cessation of rainfall earlier compared to others, indicating an earlier end to the rainy season in these areas. Conversely, areas with the latest cessation dates were Shola Gebeya (19-Sep), Shewarobit (18-Sep), Kombolcha (18-Sep), Amidework (17-Sep), Enewari (17-Sep), Gundomeskel (17-Sep), Mehal Meda (17-Sep), Majete (16-Sep), Alem Ketema (15-Sep), Mekane Selam (14-Sep), Amba Mariam (14-Sep), and Mekane Selam (14-Sep). These findings suggest that the cessation of rainfall occurred later in these regions.

Cessation dates are summarized in the table below:

Table 4. *Cessation dates by area.*

Area	Cessation date	Area	Cessation date
Alem Ketema	15-Sep	Lalibela	12-Sep
Amba Mariam	14-Sep	Majete	16-Sep
Amidework	17-Sep	Mehal Meda	17-Sep
Bati	11-Sep	Mekane Selam	14-Sep
Cheffa	11-Sep	Shewarobit	18-Sep
Debre Birhane	11-Sep	Shola Gebeya	19-Sep
Enewari	17-Sep	Sirinka	12-Sep

Area	Cessation date	Area	Cessation date
Gundomeskel	17-Sep	Tsitsiqa	31-Aug
Kobo	10-Sep	Wegeltena	27-Aug
Kombolcha	18-Sep	Wereilu	4-Sep

3.3. Length of Growing Period

Using the average LGP over the 40 years for each station, this result can be summarized as follows:

Table 5. *Average LGP of all areas.*

Alem Ketema	99	Lalibela	115
Amba Mariam	96	Majete	127
Amidework	97	Mehal Meda	103
Bati	85	Mekane Selam	99
Cheffa	92	Shewarobit	100
Debre Birhane	100	Shola Gebeya	95
Enewari	104	Sirinka	113
Gundomeskel	108	Tsitsiqa	103
Kobo	109	Wegeltena	92
Kombolcha	121	Wereilu	97

The onset of the rainy season ranges from day 140 to day 164, typically from mid-May to early June, allowing some regions to start earlier and benefit from a longer growing season. The cessation generally occurs between days 239 and 261 (early to mid-September), with most regions experiencing a synchronized end to the rainy season. Areas with an earlier onset (around day 140) have a longer growing period (over 100 days), while those with a later onset (around day 160) have a shorter growing period (85-90 days). This variation in the Length of Growing Period (LGP) affects agricultural practices, with longer LGPs supporting longer-duration crops and shorter ones requiring faster-growing varieties.

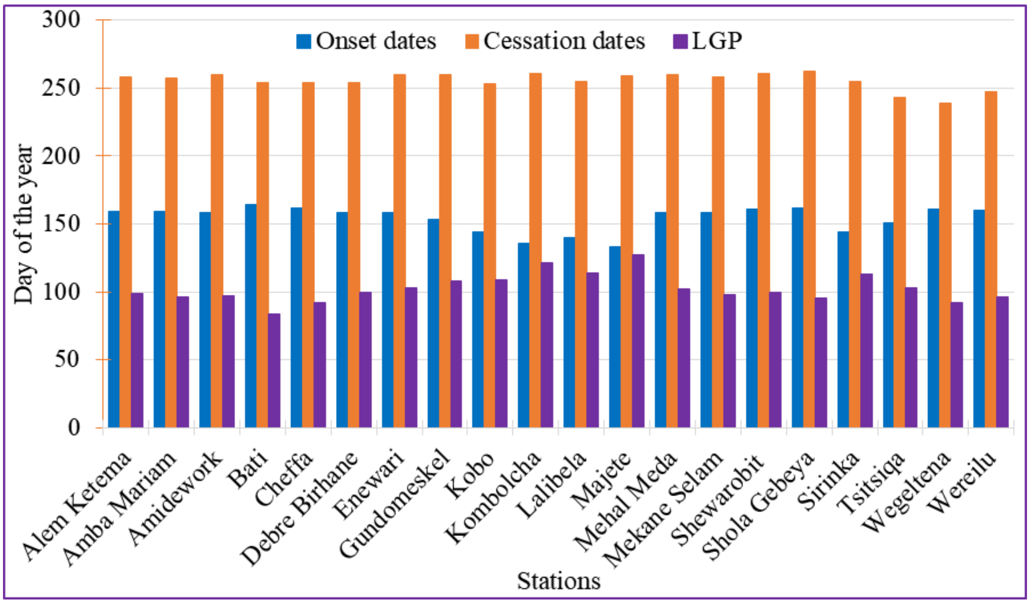

Figure 2. *Summary of onset, cessation and LGP using day of the year.*

3.4. Trend Analysis for Onset, Cessation Dates and LGP

Mann-Kendall Trend Test

The Mann-Kendall test is a non-parametric statistical test used to detect trends in time series data. This method was chosen to assess the presence of significant trends in onset, cessation dates and LGP over the study period, accounting for potential seasonality. Results from the Mann-Kendall test are interpreted to identify whether there is a monotonic increasing, decreasing, or stable trend in rainfall over time. This test is done for each station's onset, cessation and length of growing period dates previously determined over the 40 years study period and the results are discussed below.

Table 6. *Summary of the Mann Kendall test result.*

	Onset date			cessation date			LGP		
Area	**P- value**	**S**	**Kendall's tau**	**P- value**	**S**	**Kendall's tau**	**P- value**	**S**	**Kendall's tau**
Alem Ketema	0.11	-136	-0.18	0.566	50	0.07	0.07	155	0.2
Amba Mariam	0.48	-62	-0.08	0.001	275	0.36	0.05	166	0.21
Amidework	0.88	-14	-0.02	0.093	145	0.19	0.26	97	0.13
Bati	0.51	-57	-0.07	0.475	62	0.08	0.34	83	0.11
Cheffa	0.38	-77	-0.1	0.172	118	0.15	0.26	98	0.13
Debre Birhane	0.3	-90	-0.12	0.029	188	0.25	0.1	142	0.18
Enewari	0.44	-67	-0.09	0.211	108	0.14	0.23	105	0.14
Gundomeskel	0.41	-71	-0.09	0.293	91	0.12	0.1	143	0.18
Kobo	0.71	-33	-0.04	0.232	103	0.14	0.32	86	0.11
Kombolcha	0.53	-54	-0.07	0.387	-75	-0.1	0.79	24	0.03
Lalibela	0.44	-66	-0.09	0.219	106	0.14	0.14	128	0.17
Majete	0.74	-29	-0.04	0.132	130	0.17	0.01	213	0.28
Mehal Meda	0.77	-26	-0.03	0.408	72	0.09	0.53	55	0.07
Mekane Selam	0.68	-36	-0.05	0.124	132	0.18	0.32	86	0.11
Shewarobit	0.23	-103	-0.14	0.042	175	0.23	0.22	107	0.11
Shola Gebeya	0.26	-98	-0.13	0.412	-71	-0.09	0.155	123	0.16
Sirinka	0.31	88	0.12	0.018	204	0.27	0.369	123	0.15
Tsitsiqa	0.18	116	0.15	0.029	188	0.25	0.36	78	0
Wegeltena	0.14	-127	-0.17	0.157	122	0.16	0.02	209	0.27
Wereilu	0.28	-94	-0.12	0.151	124	0.16	0.13	131	0.17

P value for onset dates shows that none of the stations have a statistically significant trend because all areas have P-values greater than 0.05 meaning that there is no trend observed about the onset dates.

On the other hand, cessation dates show significant increasing trend in 5 areas (Amba Mariam, Debre Birhan, Shewa Robit, Sirinqa and Tsitsiqa) and the rest 15 areas have not shown any significant trend. The implication of this result is that there is trend of cessation dates coming late in those five areas and will remain the same with minor deviations in the rest or majority of the study area.

Length of growing period shows a non-significant trend in majority of the area. Only three stations (Amba Mariam, Majete and Wegeltena) have shown significant increasing trend. The overall image of this is that length of growing period is almost constant trend in the vast majority of the study area and only increasing in length around several places.

3.5. Trend and Variability Analysis of *Kiremt* Rainfall

3.5.1. Mann-Kendall Rainfall Trend Test

The Mann-Kendall test is a non-parametric statistical test used to detect trends in time series data. This method was chosen to assess the presence of significant trends in rainfall over the study period. Results from the Mann-Kendall test are interpreted to identify whether there is a monotonic increasing, decreasing, or stable trend in rainfall over time, providing insights into long-term climate change impacts. This test is done for eachz month, *Kiremt* season and for the total annual precipitation observed in the study area and the results are discussed below. Accordingly, all months except June have shown no significant trend with P values over 0.05. An increasing trend is only seen in June for the month June with a p-value of 0.004.

Table 7. Summary of the Mann Kendall test result.

Month	Kendall's tau	P-Value	Sen's slope
Jan	-0.087	0.435	-1.873
Feb	-0.159	0.152	-6.371
Mar	-0.144	0.196	-9.358
Apr	-0.01	0.935	-0.892
May	0.077	0.492	5.654
Jun	0.322	0.004	13.696
Jul	0.154	0.166	27.771
Aug	0.092	0.408	13.645
Sep	0.038	0.735	2.268
Oct	0.097	0.382	3.647
Nov	0.208	0.061	2.723
Dec	-0.1	0.37	-1.146
Kiremt	0.197	0.075	66.726
Annual	0.156	0.159	45.081

In addition to the statistical analysis, charts with trend lines are produced to visually represent the rainfall data over time. Using Excel's charting tools; graphs that illustrated the monthly and annual rainfall totals, along with their respective trend lines are produced. This visual representation helped highlight any significant trends and patterns in *Kiremt* rainfall, making it easier to interpret the data and assess the implications for agricultural practices and water resource management in the region. The graphs are presented below:

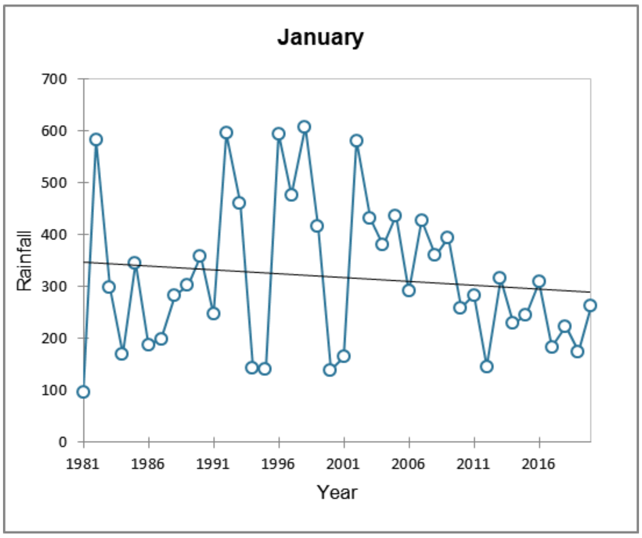

Figure 3. Mann Kendall test result for January.

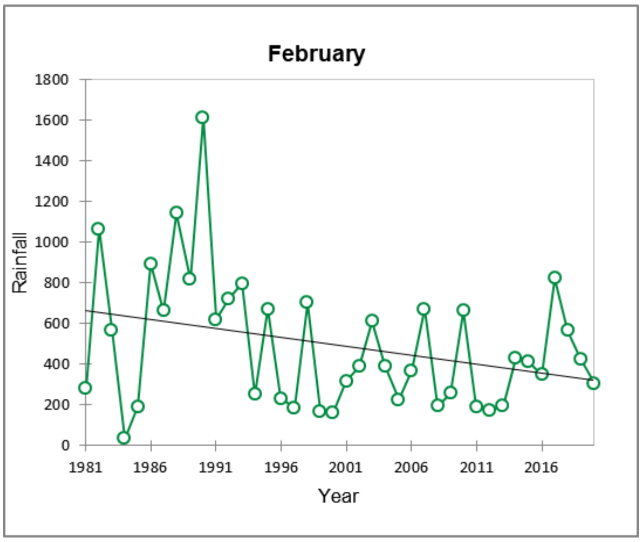

Figure 4. Mann Kendall test result for February.

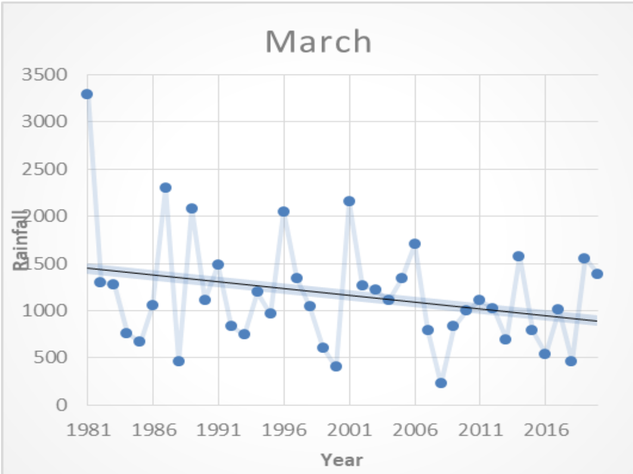

Figure 5. Mann Kendall test result for March.

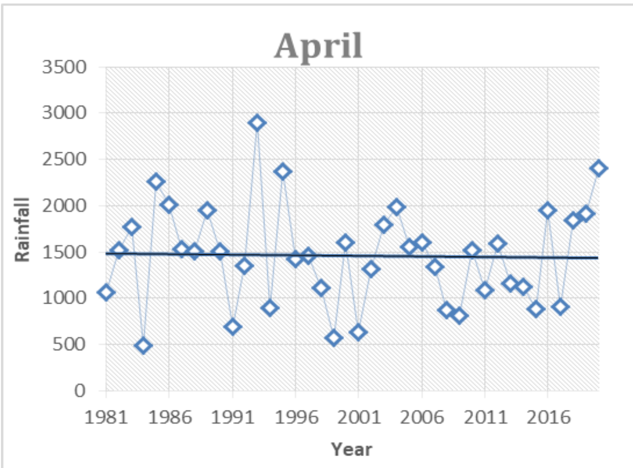

Figure 6. Mann Kendall test result for April.

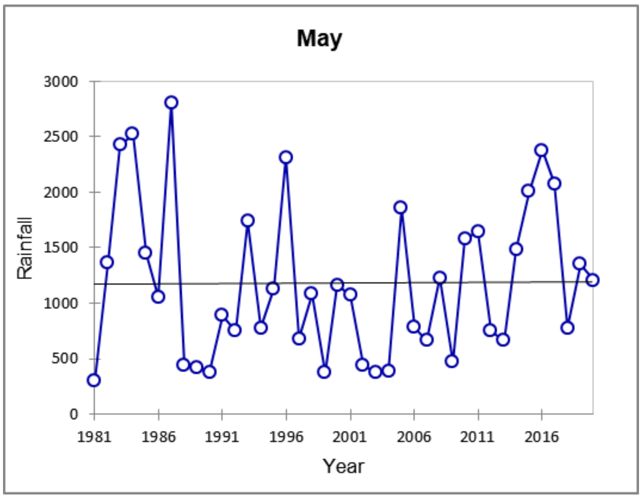

Figure 7. Mann Kendall test result for May.

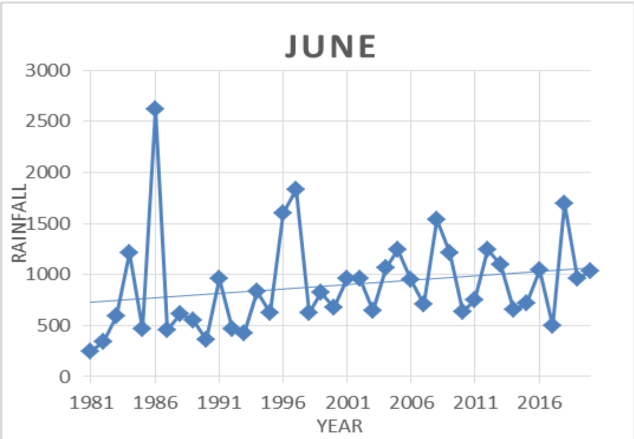

Figure 8. Mann Kendall test result for June.

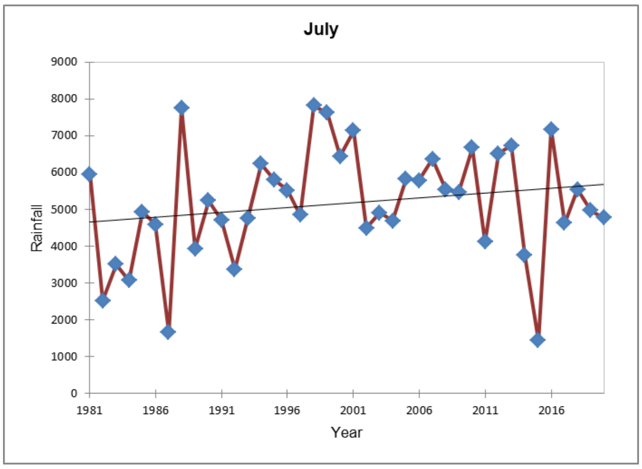

Figure 9. Mann Kendall test result for July.

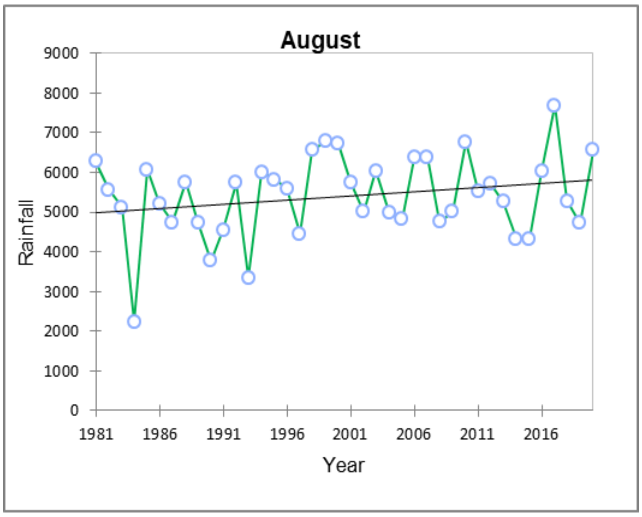

Figure 10. Mann Kendall test result for August.

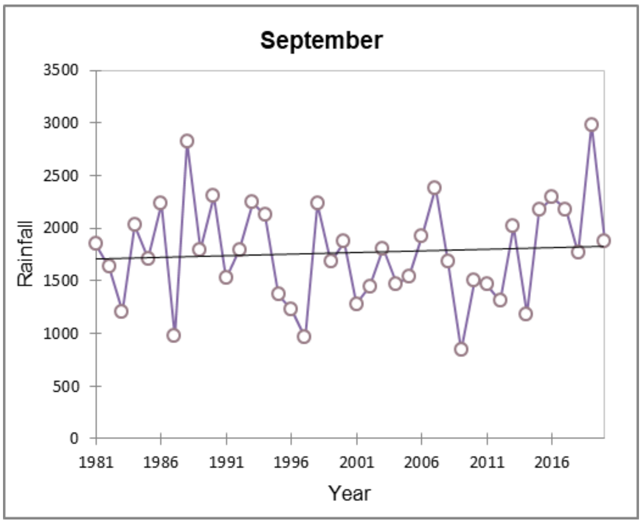

Figure 11. Mann Kendall test result for September.

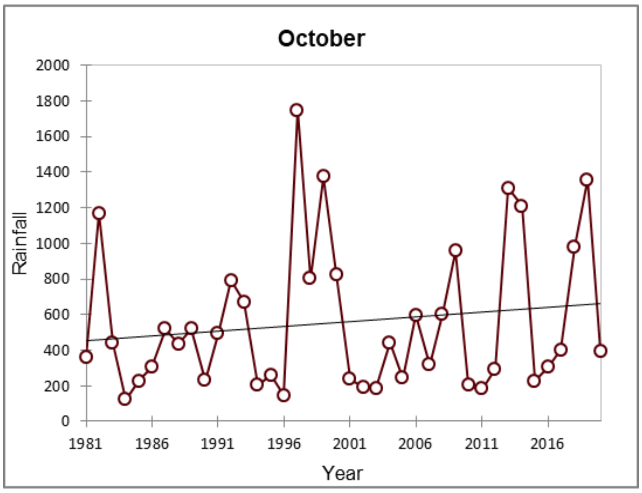

Figure 12. Mann Kendall test result for October.

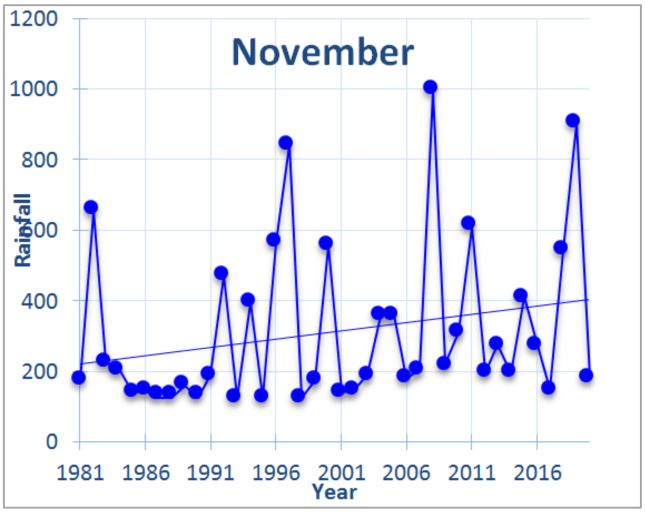

Figure 13. Mann Kendall test result for November.

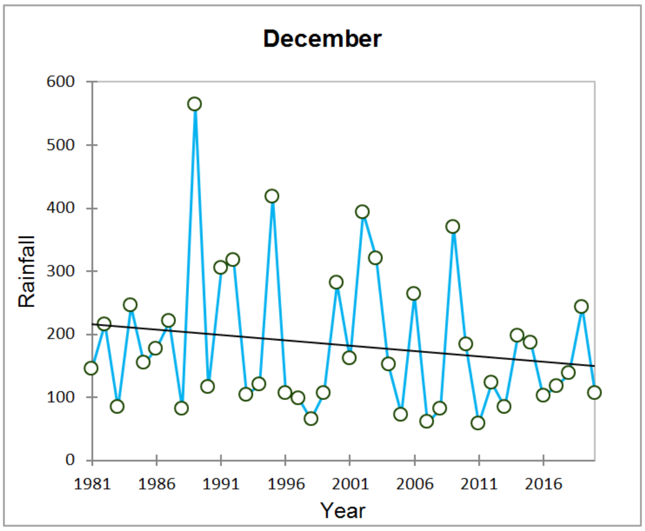

Figure 14. Mann Kendall test result for December.

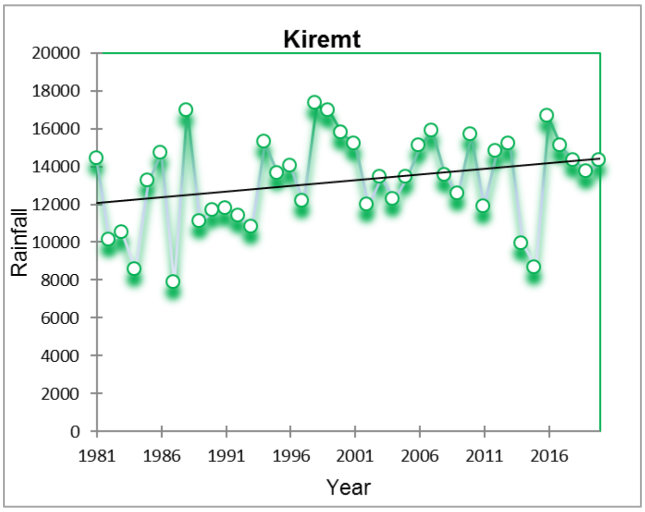

Figure 15. Mann Kendall test result for Kiremt.

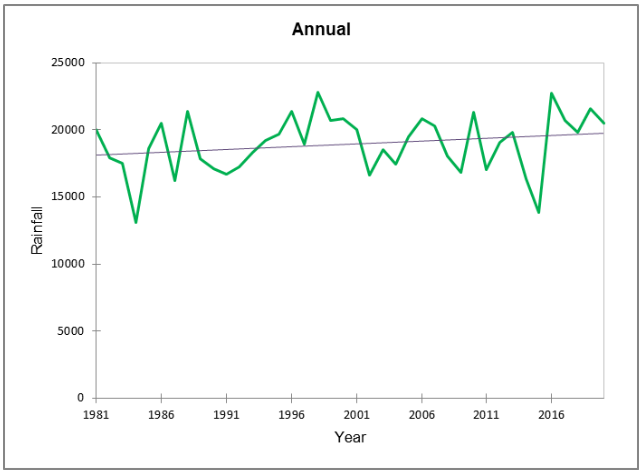

Figure 16. Mann Kendall test result/Annual.

3.5.2. Standardized Anomaly Index (SAI)

The SAI analysis revealed significant rainfall patterns across the study areas, with most locations experiencing predominantly near-normal precipitation conditions. Alem Ketema, Ambamariam, Bati, Cheffa, and Debre Birhan showed consistent trends of near-normal years, interspersed with periods of moderate to extreme wetness or dryness. For instance, Alem Ketema experienced 19 near-normal years alongside a mix of moderately wet, dry, and a few extreme events, while Bati had 23 near-normal years, indicating balanced wet and dry conditions with only two extremely dry years. Similarly, Cheffa recorded 29 near-normal years, with a few moderately and severely dry periods. Other locations, such as Kombolcha and Majete, demonstrated greater variability, with anomalies like extreme wetness in 2016 and 2007, respectively, following prolonged dry periods. These trends highlight the complex climatic dynamics influencing rainfall distribution and variability across the region.

Several areas displayed notable deviations during specific years. For example, 2000 stood out as an extremely dry year for many locations, including Lalibela, Majete, and Mehal Meda, while wet conditions were evident in years like 2010 and 2016 across several sites. Areas like Tsitsiqa and Wegeltena experienced alternating patterns of dry and wet extremes, with extremely dry years like 2015 contrasting sharply with wet years like 1998. The application of robust statistical methods, including the Mann-Kendall trend test, SAI, PCI, and CV, provided a comprehensive understanding of these trends, enabling insights into the region's climatic variability. These findings are essential for developing strategies to manage water resources, plan agricultural activities, and address the impacts of climate variability in the study area.

3.5.3. Coefficient of Variability

In Eastern Amhara, all areas except Mekane Selam exhibit a coefficient of variation (CV) value of less than 20%, suggesting a relatively consistent pattern of rainfall variability across the region. Mekane Selam stands out with a CV of 21.02%, indicating a slightly higher level of variability compared to the other areas. This analysis highlights the overall moderate to low variability in rainfall distribution across Eastern Amhara, with Mekane Selam being the exception with a slightly higher degree of variability.

Table 8. *Result of the CV analysis.*

Areas	CV (%)	Areas	CV (%)
Alem Ketema	11.06	Lalibela	15.27
Amba Mariam	16	Majete	14.14
Amdeworq	15.51	Mehal Meda	15.34
Bati	15.40	Mekane Selam	21.02
Cheffa	14.07	Shewa Robit	13.53
Debre Birhan	13.3	Shola Gebeya	12.90
Enewari	11.61	Sirinqa	15.38
Gundomesqel	11.28	Tsitsiqa	14.76
Kobo	16.92	Wegeltena	15.88
Kombolcha	15.19	Wereilu	13.99

3.5.4. Precipitation Concentration Index (PCI)

The Precipitation Concentration Index (PCI) values exhibit a wide range of fluctuation over the years, spanning from as low as 14.55 to as high as 25.81. This substantial variability underscores the dynamic nature of rainfall concentration during the specified period. Year after year, the PCI values provide insights into the diverse patterns of rainfall distribution, reflecting the decline and flow of meteorological conditions. Throughout this time frame, certain years stand out with particularly high PCI values exceeding 21. These include notable instances such as 1981, 1988, 1994, 1998, 1999, 2000, 2001, 2007, 2009, 2010, 2012, 2013, and 2017. Such years signify periods marked by very high rainfall concentration, suggesting significant disparities in precipitation across different time intervals within each year. The pronounced variability in rainfall distribution during these periods likely posed challenges for various sectors reliant on consistent weather patterns. Similarly, years with PCI values ranging between 16 and 20, encompassing periods like 1983, 1986, 1987, 1989, 1990, 1991, 1992, 1996, 1998, 2002, 2004, 2005, 2006, 2008, 2011, 2015, 2018, and 2020, denote moderate to high rainfall concentration. While not reaching the extreme levels observed in the aforementioned years, these periods still experienced significant irregularities in precipitation distribution. Such fluctuations likely posed challenges for sectors reliant on stable weather patterns, prompting the need for adaptive measures. In contrast, years characterized by PCI values below 16, such as 1982, 1984, 1993, 1997, 2014, and 2019, portray relatively lower rainfall concentration and a more uniform distribution. These years likely enjoyed more consistent precipitation patterns, with minimal fluctuations in rainfall distribution over time. Such periods of stability in rainfall distribution are crucial for sectors like agriculture, water management, and urban planning, as they provide a reliable foundation for decision-making and resource allocation.

Table 9. *Result of the PCI analysis.*

Year	PCI	Year	PCI	Year	PCI	Year	PCI
1981	22.54	1991	18.15	2001	23.23	2011	19.28
1982	15.32	1992	17.76	2002	18.97	2012	22.72
1983	16.83	1993	15.59	2003	20.31	2013	21.03
1984	15.93	1994	22.63	2004	18.50	2014	15.81
1985	20.84	1995	20.19	2005	18.17	2015	16.73
1986	16.04	1996	17.11	2006	19.70	2016	20.16
1987	16.27	1997	15.64	2007	22.09	2017	21.67
1988	23.04	1998	22.08	2008	19.05	2018	17.93
1989	16.08	1999	25.80	2009	21.17	2013	14.54
1990	18.27	2000	22.03	2010	21.93	2020	19.04

4. Implication of Rainfall Variability on Agriculture

This study aimed to determine rainfall onset, cessation, and the length of the growing period (LGP) across Eastern Amhara using data from 1981-2020 and to analyze trends and variability in these parameters. The findings revealed a consistent early June onset for most locations, with minor regional differences. For example, Alem Ketema, Amba Mariam, and Debre Birhan shared an onset date of June 7-8, while areas like Majete and Kombolcha experienced earlier rains starting in mid-May. Rainfall cessation generally occurred in mid-September, with some areas like Tsitsiqa and Wegeltena ending as early as late August, reflecting climatic diversity. Despite regional variability, the timing of the Kiremt rainy season showed no significant shifts, providing stability for agricultural planning.

Mann-Kendall trend analysis found no significant trends in onset dates across the region, though cessation dates exhibited an increasing trend in five locations, such as Debre Birhan and Sirinka. LGP showed a significant increase in three stations, suggesting extended periods for crop growth in those areas. These stable rainfall patterns hold important implications for agriculture and water resource management. Farmers can plan planting and harvesting schedules confidently without needing major adjustments, while targeted interventions like water conservation and climate-smart agricultural practices can address local rainfall variability. The study's findings align with prior research in Ethiopia, though they highlight some unique regional patterns, particularly in onset and cessation timing.

5. Conclusions and Recommendations

5.1. Conclusion

This study provided an in-depth analysis of Kiremt rainfall patterns and trends in Eastern Amhara, Ethiopia. Onset dates typically occur in early June, with variations between locations like Kombolcha and Majete, where rains may start as early as mid-May, and Alem Ketema or Amba Mariam, where onset is around June 7-8. Rainfall cessation generally happens in mid-September, though it can occur as early as late August in places like Tsitsiqa and Wegeltena. Mann-Kendall trend analysis indicates a significant shift toward earlier onset and later cessation, extending the growing period. These patterns reflect the impacts of climate change, underscoring the need for adaptive agricultural practices and effective water resource management to support food security and livelihoods.

The findings have critical implications for agricultural planning, water management, and climate resilience. The stability of rainfall patterns, except in Mekane Selam, helps farmers plan planting schedules, though increasing variability may require adjustments to crop calendars and varieties. A longer growing season can boost productivity but also heightens risks of pests and diseases. Investments in climate-smart practices, rainwater harvesting, and irrigation infrastructure are essential for mitigating risks and improving resilience. Moreover, sustainable land management and conservation efforts are vital to preserving water resources and supporting ecosystem stability amid changing climatic conditions.

5.2. Recommendations

Early warning systems to create accurate planting and harvesting calendars that match rainfall patterns. Share updated schedules with farmers, helping them optimize crop yields and avoid losses by adjusting to current climate conditions.

Encourage farmers to adjust planting schedules to optimize the longer growing season. This could involve planting crops that benefit from extended periods of growth and can maximize yields.

Introduce crop varieties that thrive in longer growing periods. Promote the planting of both early-maturing and late-maturing crops to take full advantage of the extended growing season and reduce risks associated with climate variability.

Drought-Resistant and Short-Cycle Cereals

1. Sorghum: Highly drought-tolerant and capable of thriving in areas with variable rainfall. Sorghum can be planted in the early onset period and is resilient enough to withstand drier conditions if the rainy season ends sooner than expected.
2. Millet: Another resilient crop, millet is suitable for areas with low and irregular rainfall. Its short growth cycle and low water requirements make it ideal for regions prone to early cessation.
3. Teff: Native to Ethiopia, *teff* is relatively drought-tolerant and performs well in various soil types. It can also adapt to a range of rainfall conditions, making it a staple crop choice.
4. Quick-Maturing Maize: Selecting early-maturing maize varieties (e.g., hybrids that mature in 90-100 days) ensures that the crop can reach maturity even if the season is shortened by early cessation. This variety allows farmers to benefit from early rainfall and harvest before drought risk peaks.
5. Cowpeas: Known for their resilience in dry conditions, cowpeas not only provide food but also improve soil nitrogen levels. This helps maintain soil health, which is crucial for sustainable agriculture in areas with rainfall variability.
6. Chickpeas and Lentils: These legumes are ideal for areas with lower rainfall as they require less water. They can be planted at the start of the rainy season and harvested before cessation in drier areas.
7. Sweet Potatoes: This crop tolerates a range of moisture conditions and provides food security due to its nutrient-rich roots. Sweet potatoes are suitable for regions with erratic rainfall, as they can survive both wet and dry spells.

Because the PCI result shows variability among the years, it is recommended for future investigations to assess the trend and variability of rainfall in Eastern Amhara for the coming decades using Coupled Model Inter comparison Project Phase 6(CMIP 6).

Abbreviations

CHIRPS	Climate Hazards Group InfraRed Precipitation with Station Data
CV	Coefficient of Variability
ENSO	El Niño-Southern Oscillation
IOD	Indian Ocean Dipole
ITCZ	Inter-Tropical Convergence Zone
MK	ManKendall
NAO	North Atlantic Oscillation
PCI	Precipitation Concentration Index
SAI	Standardized Anomaly Index

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Author Contributions

Abraham Amehse: Conceptualization, Data curation, Analysis, Methodology, Software, Writing – original draft

Tilahun Sewagegn: Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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