Analysis of Rainfall Variability for Mekelle Meteorological Station, Northern Ethiopia (1960-2009)

Girmay Abreha Weldesenbet
Raya University, P.O.BOX: 92

Abstract

Nowadays rainfall variability is threatening the world. Despite this, studies related to the determination of variations, trends and fluctuations of rainfall have little local and regional specificity. Hence, this study aimed to analyze the trend and variability of the annual and seasonal rainfall occurrence at Mekelle Airport meteorological station, Northern Ethiopia. Historical rainfall data for the period 1960-2009 of the rain gauge station were obtained from National Meteorological Service Agency. Annual, seasonal and monthly rainfall trends; onset and cessation date of kiremt rainfall; growing period length and the number of rainy days and dry spell length were considered. Standardize anomaly index (SAI) and coefficient of variance was employed to analyze the rainfall data variability using INSTAT plus, SPSS version 20 and Excel. Analysis of the historical data showed extremely severe drought happened in the area in 1984 which resulted in the death of one million people, 8 million people highly affected, and 2.3 million people food in secured. 1961 was an extremely wet year. Generally, 70%, 18% and 12% years were normal, dry and wet respectively for the last 50 years. High annual, seasonal and monthly rainfall variability was observed. Though the station showed both increasing (1984-1988) and decreasing trends (1961-1968) of annual rainfall totals a declining trend was more pronounced. Besides, one to two weeks variability on the onset and cessation date was observed. The minimum and maximum kiremt season rainy days recorded in 1987 (27days) and 1986 (86 days) respectively while the maximum dry spell days recorded in the 50 years was in 1969. Thus, devising agronomic practices that retain moisture at the plant root zone and reduce crop failure due to variability of rainfall including extended dry spell could be important.

Introduction

Earth's climate is changing and varying (Sathyanathan et al, 2019). Rainfall variability is becoming a global challenge. This rainfall variability is due to seasonal atmospheric phenomenon and geographic factors (Amrutha and Shreedhar, 2014). Temporal distribution of rainfall plays a fundamental role in water resources management. Monthly and seasonal data are employed in determining supplementary irrigation water requirements, and in engineering studies related to storage analyses, water supply, and reservoir management. Besides, agricultural production, water supply, transportation and economic development can be affected by the variability of rainfall. Generally, analyzing rainfall data is critically important for agricultural planning; design of storage structures; study the trends in rainfall series; planning and management of the water resources; study the occurrences of droughts and floods; structural characteristics of annual rainfall and temporal variations of rainfall (Emaziye and Okoh, 2012; Gajbhiye et al, 2016; Ganguly et al, 2015; Getachew and Teshome, 2017; Amrutha and Shreedhar, 2014).

In regions where variability is high, people suffer from disasters due to extreme events. The damage due to these extremes of rainfall cannot be avoided completely, a forewarning could certainly be useful and it is possible from analysis of rainfall data. Rainfall frequency analysis is therefore helpful to predict its impact on different spheres. To identify and quantify the change and variability in rainfall, many global studies have been carried out. Studies conducted in the Mediterranean region for the period 1918–1999 show a negative trend in precipitation (Longobardi and Villani, 2009). Emaziye et al (2012) observed rainfall values decreasing with an increasing rate in Delta state, Nigeria. While a study in Turkey showed the annual precipitation is not significantly increasing (Hadi and Tombul, 2018; Rahman et al, 2017). Hussain et al, (2015) reported a positive trend at the annual and seasonal scales and negative trend at the spring, pre-monsoon and post-monsoon seasons. Mohamed et al (2019) in Peninsular Malaysia found an increment in utmost rainfall totals.

Caloiero (et al, 2018) in Southern Italy noted that highest and the lowest rainfall values come out. Makuei et al, (2013) have examined rainfall increase in the northwest and decrease in the eastern and southwestern of Australia since the 1950s. On the other side, Rustum et al, (2017) in Shire, Malawi, reported an increasing trend of annual precipitation. Gajbhiye et al, (2016) also reported similar findings in Shindh River basin in India. (FEWS NET, 2012) investigated *15–20 per cent decline of Spring and Summer rains in Ethiopia. In contrary,* Gedefaw et al, (2019) observed increasing annual rainfall trend in Gonder, Ethiopia.

Despite this, studies related to the determination of variations, trends and fluctuations of rainfall have little local and regional specificity. Besides, rainy days frequency and rainy season duration were studied very little.

Thus, this study was conducted to fill such a knowledge gap. Because of this, an attempt has been made to study the temporal behaviour of rainfall in Mekelle airport rain gauge station of Tigray regional state, northern Ethiopia. Therefore, the main objective of this study was to analyze the trend and variability of the annual and seasonal rainfall occurrence at Mekelle Airport station. This has been achieved by considering historical data for the period 1960-2009 of the rain gauge station.

2. Materials and Methods
2.1 Study area
The study was conducted in Mekelle Airport meteorological station, Northern Ethiopia. The station is located at 13° 28'N latitude and 39° 32' E longitude. The station is located at Mekelle the capital of Tigray regional state. The altitude of the Mekelle airport meteorological station is 2084 meters above sea level (m.a.s.l). The climate of the area is mainly characterized as a semi-arid and has flat land dominated topography. The main rainy season summer (locally called *kiremt)* lasts for 2 to 3 months. Moreover, the area also gets a small rain shower in the spring season (locally known as *Belg*) from February to May. There is great inter-annual temporal rainfall variation.
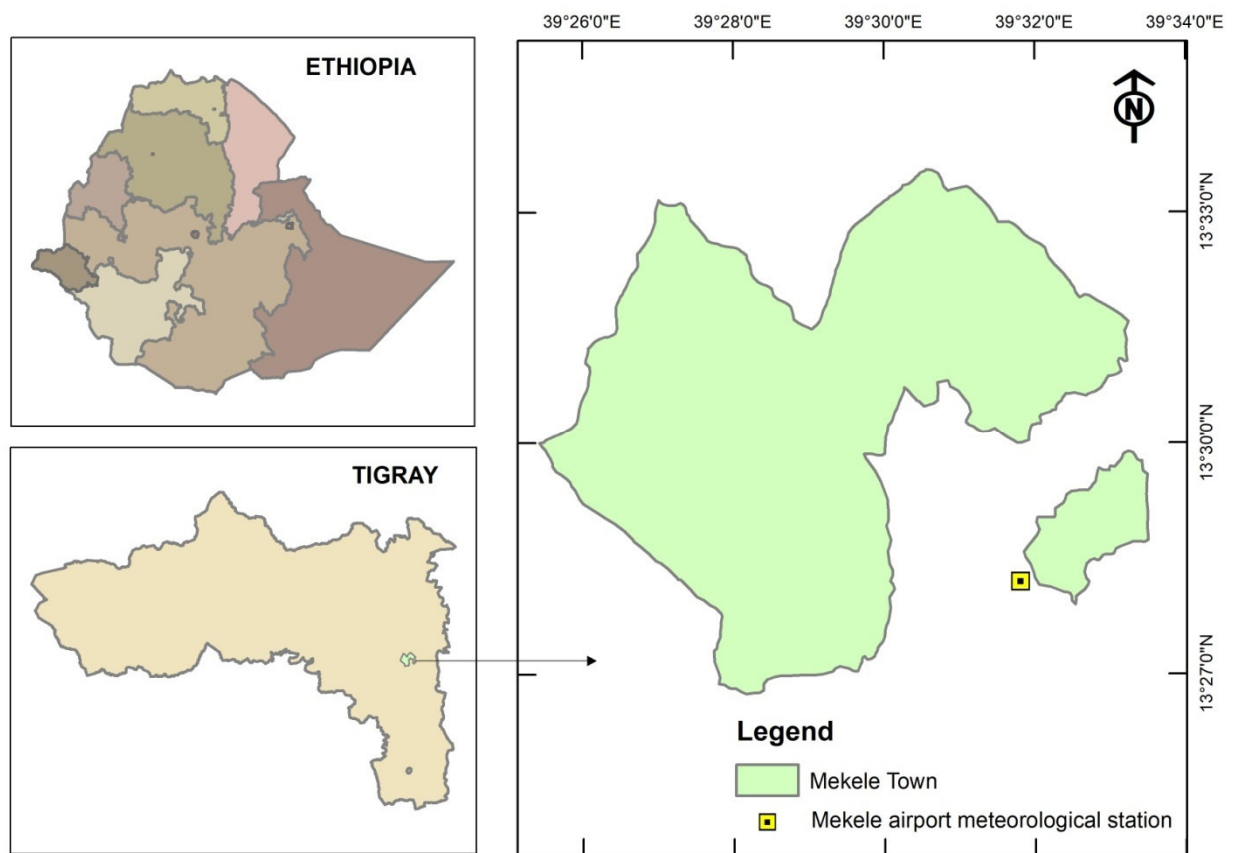

Figure 1: Mekelle Meteorological Rain gauge Station.

2.2 Materials and Methods
Daily rainfall data of the station were obtained from the National Meteorological Service Agency for 50 years from 1960-2009. The station was selected based on the length of a record period and the relative completeness of the data considering the maximum flexible thresholds of 10% missing values. To reconstruct the gap and to fill the missing values, data were generated following the first-order Markov chain model using INSTAT plus (v3. 6) Software.

INSTAT plus, SPSS and Excel were used to analyze and summarize the daily data into monthly, seasonal and annual totals and extreme events. The fluctuations were observed by using statistical interpretations and trends. In the variability analysis annual and seasonal rainfall patterns; standardize anomaly index (SAI); annual and seasonal rainfall trends mainly kiremt and Belg rainfall; monthly rainfall trends; onset and cessation date of kiremt rainfall; growing period length kiremt and Belg rainfall and number of rainy days and dry spell length in kiremt and Belg rainfall were considered.

Variability Analysis

Standardized Anomaly Index (SAI) was calculated as the difference between the annual total of a particular year and the long term average rainfall records divided by the standard deviation of the long term data.

$$Z = \frac{(x - \mu)}{Std}$$

Where, Z is standardized rainfall anomaly; x is the annual rainfall total of a particular year; μ is mean annual rainfall throughout observation and Std is the standard deviation of annual rainfall for observation. This index used to examine the nature of the trends to determine the dry and wet years in the record.

Tshiabukole et al. (2016), used the classification system shown in the standardize anomaly index (SAI) value produced by Mckee, et al, (1993) to define drought intensities resulting from the SAI. They also defined the criteria for a drought event for any of the time scales. A drought event occurs any time the SAI is continuously negative and reaches an intensity of -1.0 or less (Table 1). The event ends when the SAI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and an intensity for each month that the event continues. The positive sum of the SAI for all the months within a drought event can be termed the drought's magnitude.

Table 1. Anomaly index values of the SAI

1	2.0+	extremely wet
2	1.5 to 1.99	very wet
3	1.0 to 1.49	moderately wet
4	-.99 to .99	near normal
5	-1.0 to -1.49	moderately dry
6	-1.5 to -1.99	severely dry
7	-2 and less	extremely dry

Precipitation Concentration Index (PCI) was also used to see the temporal pattern of rainfall (Oliver, 1980)and it was computed.

$$PCI = \frac{\sum_{i=1}^{12}(Pi)2}{[\sum_{i=1}^{12}Pi]2} X100$$

Where *Pi* is the rainfall amount of the *ith* month, PCI values below 10 indicate uniform monthly rainfall distribution; values between 11 and 20 indicate high concentrations of monthly rainfall distribution, and values of 21 and above indicate a very high concentration of monthly rainfall distribution.

3. Result and Discussion

Annual Rainfall Analysis

Analysis of historical rainfall data using the SPI is useful for demonstrating the characteristics of a station about aridity and to monitor drought events. Therefore, SPI analysis was conducted for Mekelle meteorological station historical data. Drought is becoming a common feature of the station as part of the northern region. This historical data analysis shows in 1984 (-2.11) extremely severe drought happened in the area (Table 2). As noted by Hayes et al, (2000) such an extremely dry condition (SPI ≤ -2) happens about two to three times in a century. This intense drought covers all regions of the country but the most affected were eastern and southern Tigray, north Wollo and North Shewa.

Table 2. The Rainfall anomaly index of the Mekelle meteorological station

Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
SAI	0.46	3.32	0.92	-0.03	0.75	-0.56	-0.9	0.48	-1.05	0.03
Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
SAI	0.23	-1.11	-0.3	-0.81	-0.66	1.07	-0.35	0.48	-1.09	-1.55
Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
SAI	2.03	0.06	-0.14	0.63	-2.11	-0.44	0	1.025	2.05	0
Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SAI	0	0.07	-0.55	0.74	0.32	0.36	-0.16	-0.39	0.96	0.72
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SAI	-1.03	-1.455	-0.94	-0.55	-1.19	0.02	1.34	0.53	-1.64	-0.99

This drought was the leading in its devastating impact exacerbated one million people dead, 8 million people highly affected, 2.3 million people food in secured, the drought extended by a year which in turn cause death of additional 250,000 people (Mera, 2018). Over the last 50 years, the area has also experienced severe droughts in

1979 (-1.55) and 2008 (-1.64) and many moderate droughts lasting several years in 2004, 1978, 2001, 2000 and 1971 along with even more droughts of shorter duration (Table 2). Whereas 1961 (3.32) and 1988 (2.05) were extremely wet years. Generally, 70% (35 years), 18% (9 years) and 12% (6 years) were normal, dry and wet respectively for the last 50 years. Agricultural, energy, environmental, transportation, and social sector were considerably impacted by the droughts.

As defined in section 2.2 PCI value 21 and above indicate a very high concentration of monthly rainfall distribution. The annual PCI value for Mekelle metrological station is 26.29 indicating the poor monthly distribution of the rainfall (Table 3). Belg rainfall in the region showed very high interannual variability (PCI > 66%). Comparing the seasonal variability of rainfall in the station, belg rainfall is more variable than the kiremt rainfall. The direct effect of high annual and seasonal variability rainfall on agricultural production could tremendously affect the livelihood of the farming community in the area.

Table 3: Statistical characteristics of rainfall data of Mekelle meteorological station (1960 - 2009)

Characteristics	Rainfall statistics (1960-2009) for Mekelle meteorological station									
	Total	%	Mean	Median	Min.	Max.	Range	Std.	Variance	PCI%
Annual	30491.1	100	609.8	609.8	293.2	1108.9	815.7	150.4	22622.64	26.29
Annual rainy days	3482	100	69.64	65.5	41	129	88	20.41	416.72	29.31
Kiremt season	24239.79	79	484.8	449	212.4	912.7	700.3	137.8	18995.29	28.4
Kiremt dry spell days	439	2.4	8.78	8	2	19	17	4.18	17.52	58.99
Kiremt rainy days	2536	73	50.72	48	27	86	59	13.5	182.2	26.66
Kiremt onset date			6-Jul	11-Jul	16-Jun	31-Jul	15.00	1.60	4.2	
kiremt cessation date			11-Sep	13-Sep	2-Sep	15-Sep	13.00	2.8	7.8	
Belg season	4684.5	15	93.69	89	15.39	155.4	140	31.2	130.9	66
Belg rainy days	689.5	20	13.76	11.5	2	40	38	9.51	90.43	69.11

The statistical analysis of rainfall (Table 3) shows an insignificant difference between mean and median of the annual and belg season rainfall but is asymmetrical for the kiremt season. The range in the annual, kiremt and belg season is very high. The annual and seasonal rainfall PCI value is extremely variable which is 26.29%, 28.42% and 66% for the annual, kiremt and belg seasons respectively. Based on the annual and seasonal data, one can become aware of the severe irregularities in rainfall.

In Mekelle, meteorological station rainfall is low and varies from 261mm (1984) to 1107.91 mm (1961) (Figure 2). The main rainy season (kiremt rainfall) contributes largely to the annual rainfall totals in the station, its contribution was 79 % out of the total rainfall from 1960 up 2009. *Belg* rainfall also makes a considerable contribution to the annual rainfall by 15%. At the station, both increasing (for example from 1984-1988) and decreasing trends (1961-1968) of annual rainfall totals were observed. This might be due to large inter-annual fluctuation of rainfall. For instance, at Mekelle, the 1984s were generally a dry period relative to the preceding decade and rainfall recovered to more humid conditions during the 1990s that again decreased to below long term average in 1961. Thus, the analysis that ends during the late 1971s or early 2009s might show a declining trend, whereas, if the period is extended, the trend in annual rainfall totals could reduce. On the other hand, rainfall at Mekelle showed consecutive 1 to 4 year periods with wet and dry years alternatively with no apparent trend (Figures 2, 3 and 4).
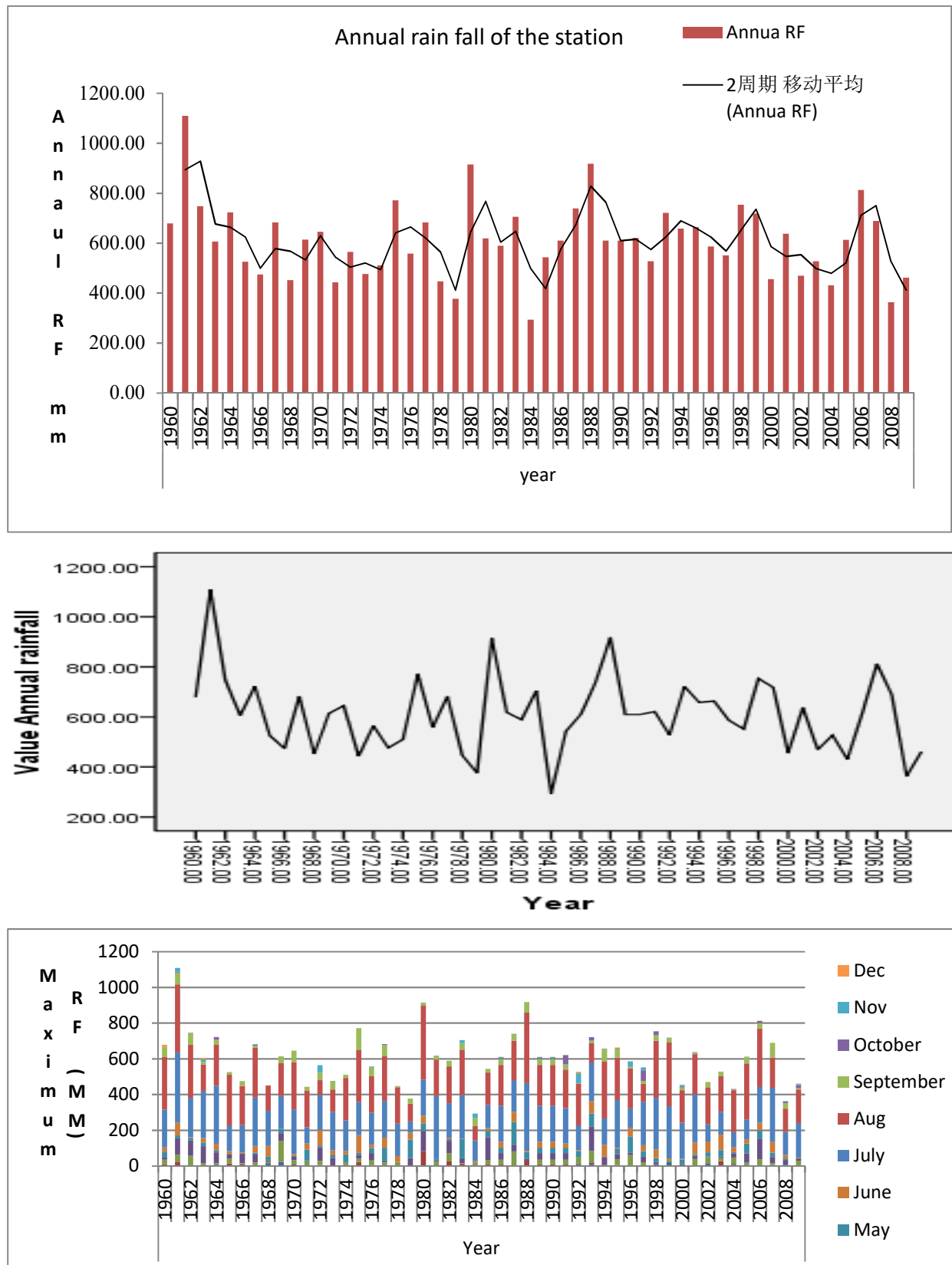
Figure 2: Annual rainfall trend of the Mekelle Meteorological station
Seasonal rainfall trend of Mekelle Meteorological Station
Based on major elements of climate, the study area has four seasons Kiremt (June 16-September 15), Meher (September 16-December 15), Bega (December 16- March 15), and Belg (March 16-June 15) seasons. The Kiremt season receives heavy rainfall (79%) followed by Belg season (15%) and Meher season with little rains (Table 3

and Figure 5). The Bega is a dry season. The seasonal rainfall varied from 212.4 – 912.7 mm in Kiremt, 13.39 – 155 .4 mm in Belg, 13.67 - 102.83 mm in Meher, and 0 - 80.5 mm in the Bega (Figure 5). From the analysis (Figure 5) a decline rainfall trend in the Kiremt season can be observed. It was seen that the decreasing of rainfall in kiremt season could be probably because of the westerly winds lose their energy before reaching the drought-prone areas including Mekelle. The analysis also shows a high variability of rainfall within and across the seasons. The results of this study are consistent with the findings of Gedefaw et al. (2019). Kiremt rainfall variability is associated with crop production.
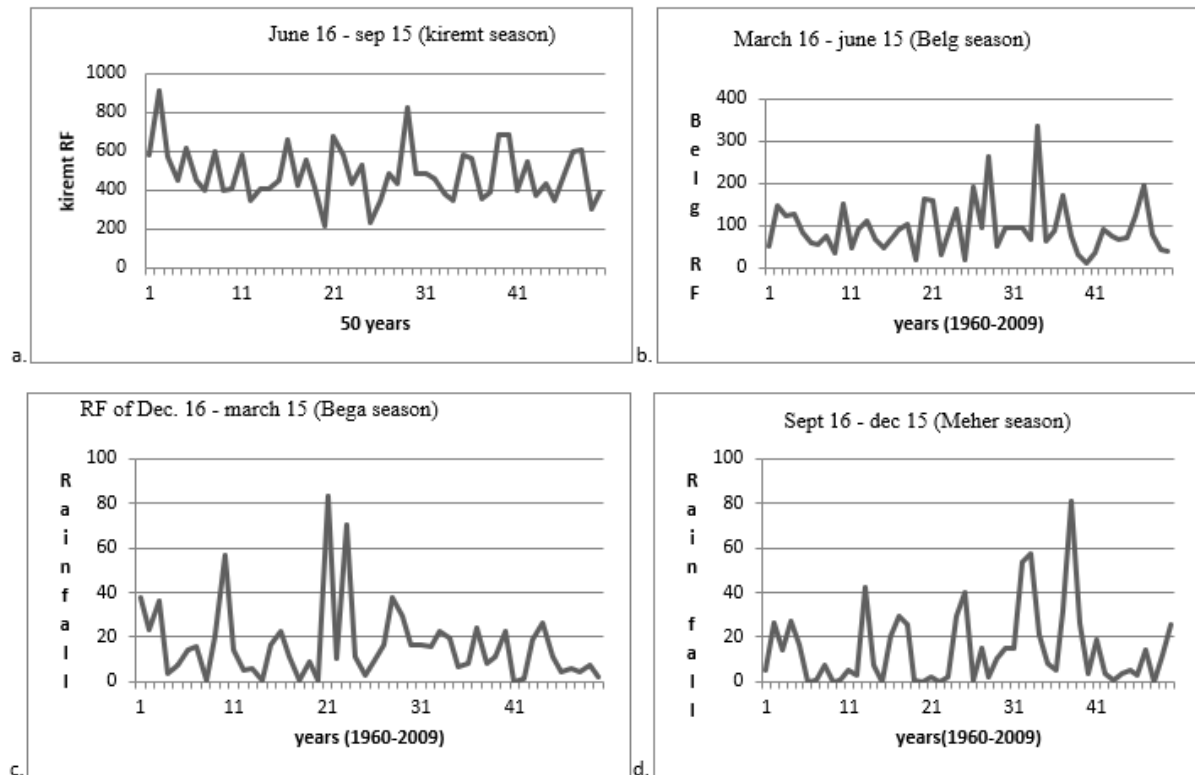
Figure 3: Seasonal rainfall trend of the Mekelle Meteorological station
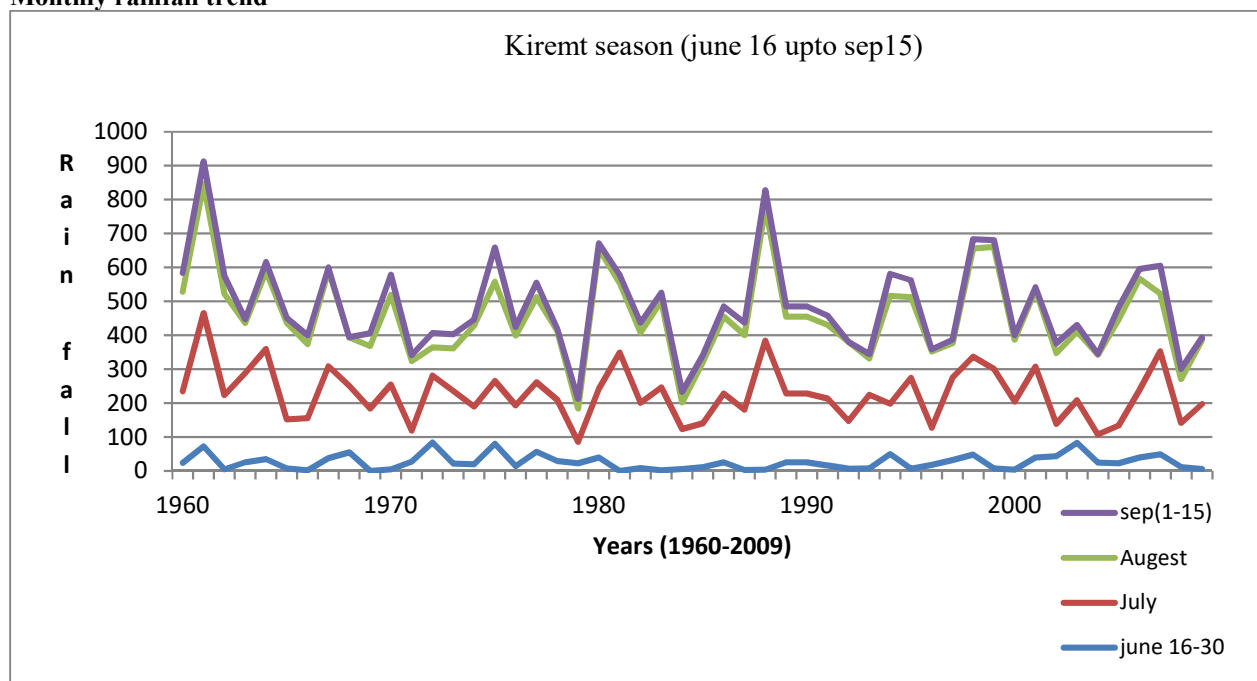
Monthly rainfall trend

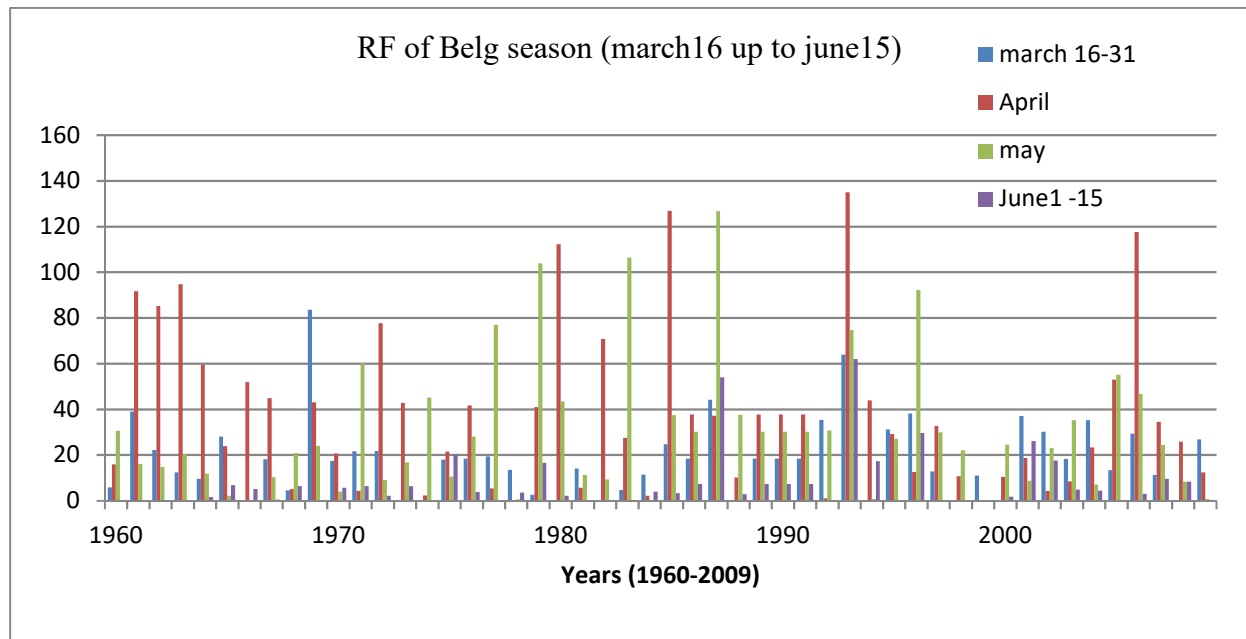Figure 4: Monthly rainfall trend in the Kiremt season

Figure 5: Monthly rainfall trend in Belg season

Kiremt rainfall onset date

Different authors use different threshold values to determine the onset and cessation of the rain. The criterion used in this study was a rainfall of 20 mm or more accumulated over three consecutive rainy days after a specified date (in this case half June) with no dry spell greater than 7 days in the next 30 days(Bello, 2008).

Results of this study (Figure 6) showed that the most frequent onset of kiremt rainfall was on the first of July. It was also characterized with high fluctuation of onset (June 16 - July 31); variability of the onset and retreat of rain; mainly a delay of 1 or 2 weeks in the onset; greater variability at the onset and retreat of rainfall than in the mid-season causing shortening of the rainy season and late-season drought. The variations in the onset date sometimes extended up to 70 days (10 weeks) from one year to another. Furthermore, the patterns could not be easily understood, make decisions about crop planting and related activities difficult.
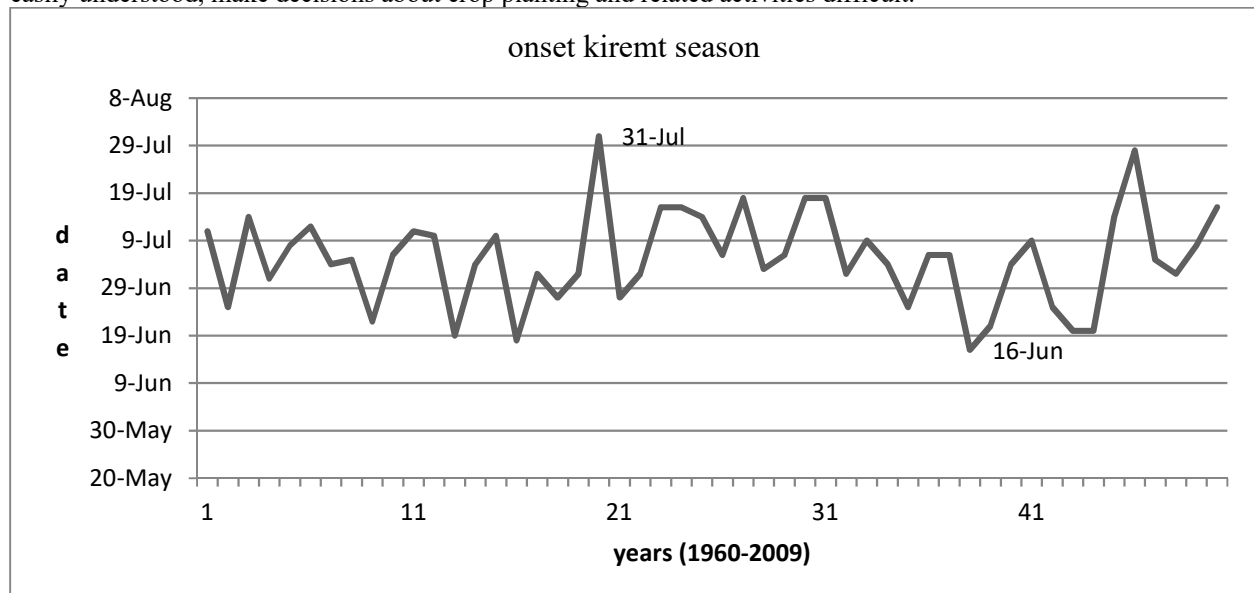

Figure 6: Onset date of the Kiremt season

Cessation date

The end of the season was defined as the date when the available soil water content dropped to 10 mm m^{-1} of available water (Hadi & Tombul, 2018). This date was set based on farmers' information obtained during a preliminary survey. But in this study cessation date assigned the last date where the rain showers ended. Results of this study indicated that the median date of the end of the kiremt season was characterized by the low standard deviation (<10 days) at the station and hence, the end of the rainy season in this station is variable from 2 September

in 1969 to 15 September in 1990 (Figure 7). Moreover, a fluctuated trend has been observed in the cessation of kiremt rainfall in the station. Onset and cessation date have affected the growing period length. The length of the growing period was calculated as a difference between the onset date and date of the end of the season. It is the year during which rainfall distribution characteristics are suitable for crop germination, establishment, and full development. It is the year categorized as the rainy or wet season the length of which varies spatially, temporally, and with crop type. The average length of the growing period in the study region varies from 66 to 85 days. Correlation analysis of LGP with onset date and end of the rainy date showed a strong relationship in the station.
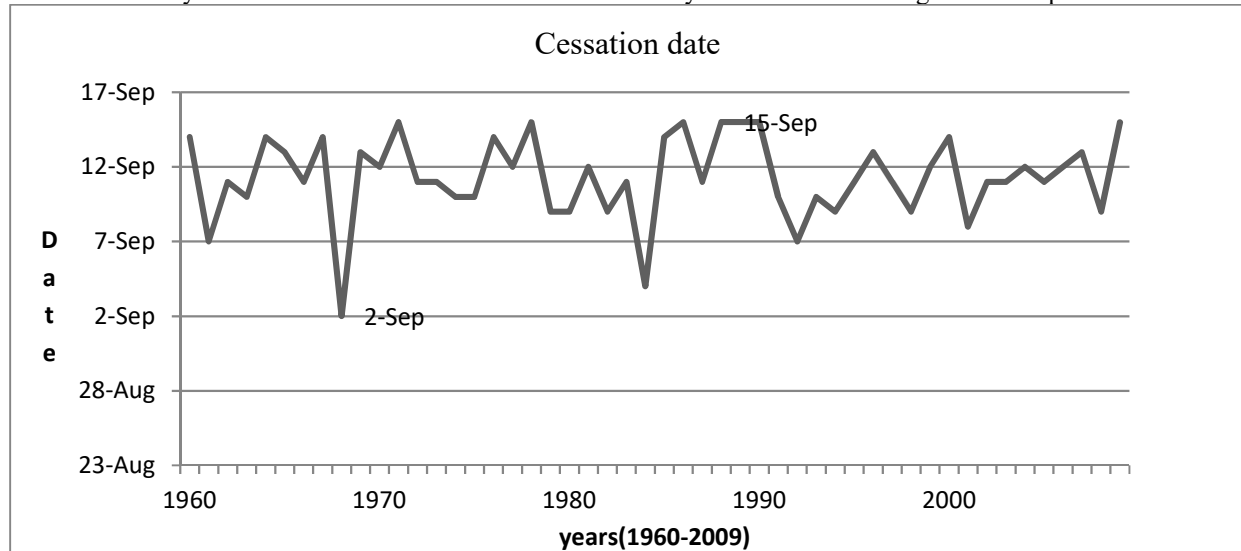

Figure 7: Cessation date of Kiremt season

Number of rainy days

Based on NMSA (2001), a day is considered as a rainy day if it accumulates 1 mm or more rainfall. The number of rainy days in *kiremt* season was, therefore, counted in each year. The number of annual rainy days observed in the station from1960 to 2009 was 3482 with 41 days minimum (1984) the extremely dry year and 129 days maximum (1986) the extremely wet year (Figure 8). The minimum and maximum Kiremt season rainy days were 27 (1987) and 86 (1986) respectively. While the minimum and maximum Belg season rainy days were 2 (1999) and 40 (1986, 1989, 1990, and 1991) respectively indicating high variability of rainfall in the last five decades.
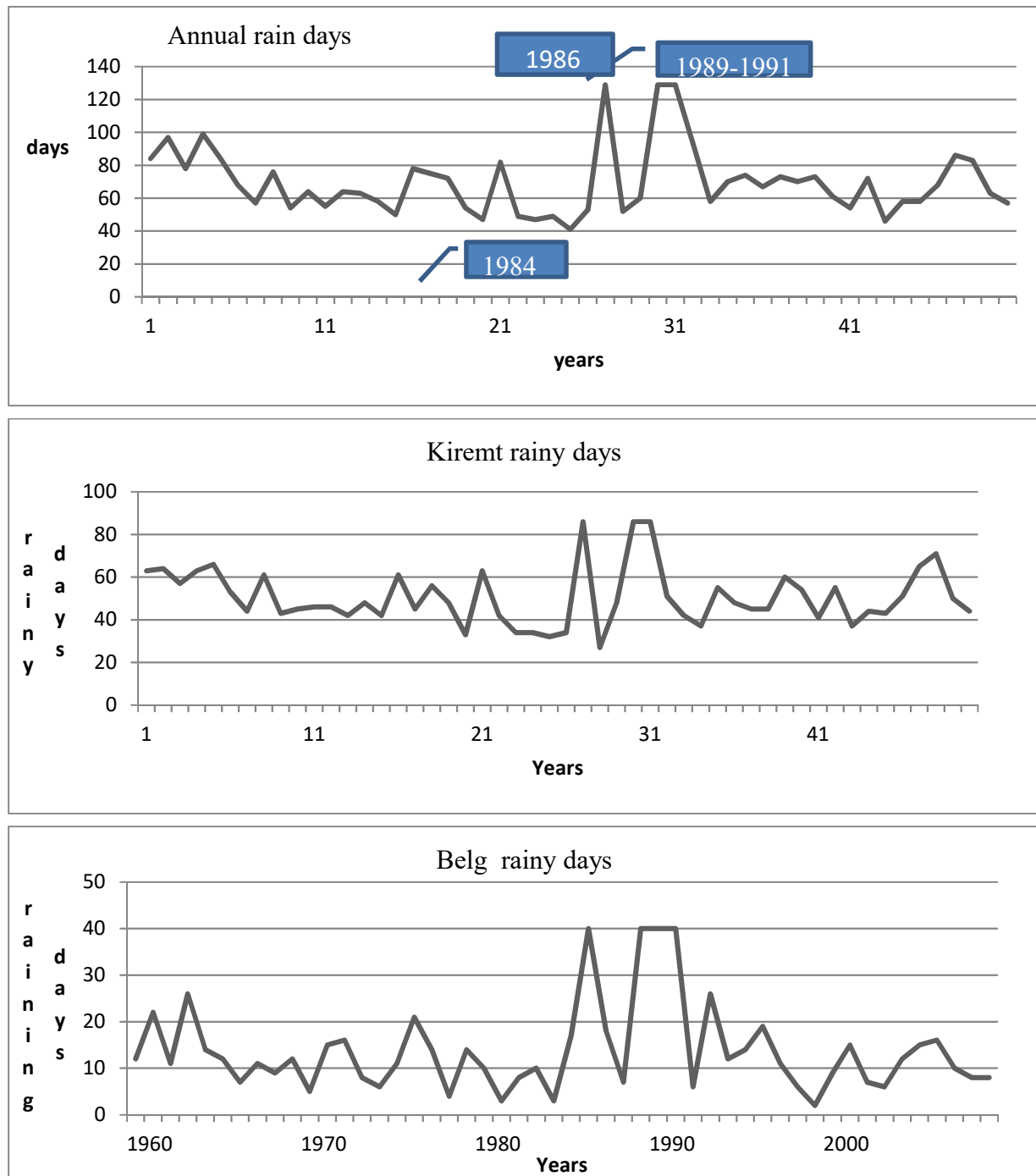
Figure 8: Rainy days
Dry spell length

According to NMSA (2001), a dry spell is a maximum number of consecutive dry days (a day that accumulates rainfall <1 mm) were counted to determine dry spell length in *kiremt* season. The 50 years average dry spell during the kiremt season over the station was generally long that is 8 days and there was a variable dry spell trend (minimum 2 in 1986 to maximum 19 dry spell days in 1969) in the station. Hence, it could be helpful to devise agronomic practices that retain moisture at the plant root zone and reduce crop failure due to the extended dry spell.
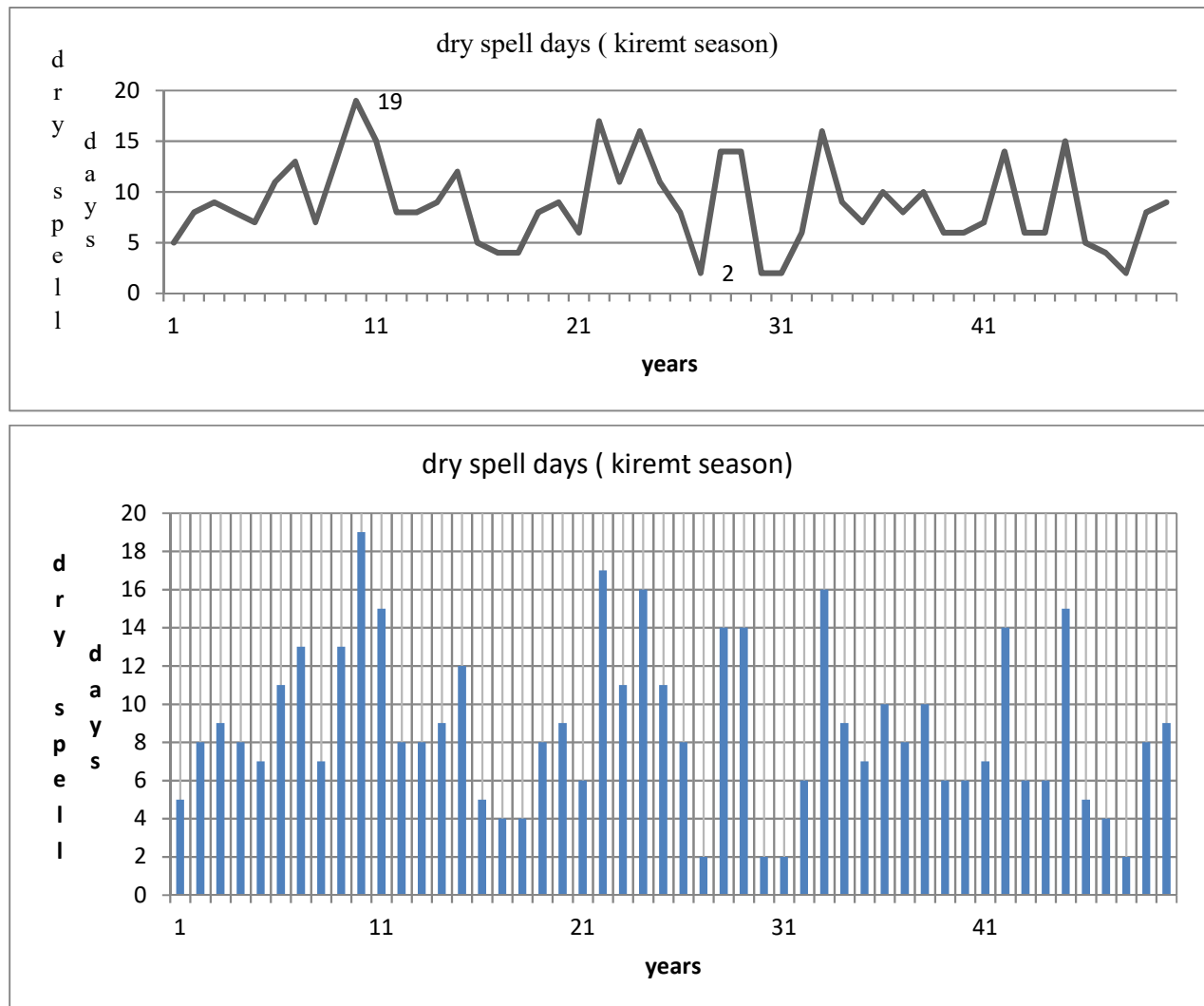
Figure 9: Dry spell days

Conclusions

Nowadays rainfall variability is threatening the world. Despite this, studies related to the determination of variations, trends and fluctuations of rainfall have received little attention. Thus, this study aimed to analyze the variability of rainfall occurrence at Mekelle Airport meteorological station, Northern Ethiopia. In the meteorological data history of the station extremely severe drought was recorded in 1984 which resulted in the death of one million people, 8 million people highly affected, and 2.3 million people food in secured. On the other side, 1961 was an extremely wet year. Generally, 70%, 18% and 12% years were normal, dry and wet respectively for the last 50 years. The station has high annual, seasonal and monthly rainfall variability. Though the station showed both increasing (1984-1988) and decreasing trends (1961-1968) of annual rainfall totals a declining trend was more pronounced. Besides, one to two weeks variability on the onset and cessation date was observed. The minimum and maximum kiremt season rainy days recorded in 1987 (27days) and 1986 (86 days) respectively while the maximum dry spell days recorded in the 50 years was in 1969. The high variability of rainfall suggests the growing importance of climate-smart agronomic practices that retain moisture at the plant root zone and reduce crop failure due to variability of rainfall including extended dry spell.

Conflict of Interest: the author declares no conflict of interest.

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