Characterizing the Climate System of Western Amhara, Ethiopia: A GIS Approach

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Abstract

The study to characterize the climate systems (rainfall and temperatures) was conducted in Western Amhara, Ethiopia. Long years (1979-2008) climate data (daily rainfall, daily maximum and daily minimum temperature) were collected from five meteorological stations of Western Amara. Following data quality checking and inspection, the daily rainfall, minimum and maximum temperature data of the selected stations was arranged in Microsoft Excel Spread Sheet and analyzed using INSTAT v3.6 and ArcGIS9.2 software. Statistical tools like; precipitation concentration index and Spearman`s rank-correlation method was used to identify the variability of rainfall concentration and test the degree of variability of rainfall and temperatures. The study revealed that the contribution of *kiremit(Long rainy season from June to September)* rainfall to the annual total rainfall was very high in all study stations. Variations of minimum and maximum temperatures were found in every month. The long term recorded rainfall data indicated an increasing trend during 1995-2008 and decreasing trend during 1979-1994, except, inter-annual fluctuation. Further, late onset and early cessation of rainfall was noted in all study stations in recent years. The spatio-temporal variability of rainfall, minimum temperature and maximum temperatures observed in the study stations are alarming. However, for improving precision and reliability of the application of the findings for practical use, increasing numbers of the study stations and periods would be crucial.

Key words: Amhara, Spatio-temporal, Kiremt,

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INTRODUCTION

The climate is important for development but natural climate fluctuations from autonomous climate cycles disrupting ecological, economic and social systems. However, human factors have an impact on local and global climate patterns. Continued rates of high population growth, increasing reliance on fossil fuel-driven growth technologies, and, land use effects, (particularly urbanization, agriculture and deforestation) causes global climate change, largely due to increases in concentrations of atmospheric greenhouse gases and aerosols (Seth, 2007).

Whereas climate change is global in nature, potential changes are not expected to be globally uniform; rather, there may be dramatic regional differences. The six warmest years in Africa have all occurred since 1987, with 1998 being the warmest year. This rate of warming is not dissimilar to that experienced globally, and the periods of most rapid warming the 1910s to 1930s and the post-1970s occur simultaneously in Africa and the rest of the world (Hulme *et al*., 2001).

Arguably one of the most widespread and potentially devastating impacts of climate change in East Africa will be changes in the frequency, intensity, and predictability of precipitation and Temperature. Changes in regional precipitation will ultimately affect water availability and may lead to decreased agricultural production and potentially widespread food shortages (Michael, 2006).

According to studies, climate variability has various impacts on the country's economy and health of the population, such as floods, droughts, or tropical storms. These disruptions can take a major toll on a country's economy. Particularly a significant part of economic activity is sensitive to the weather and climate. Ethiopia provides a good example of the influence of climate variability on a developing country's economy. GDP in Ethiopia rises or falls about a year behind changes in average rainfall. With agriculture accounting for half of GDP and 80% of jobs, the Ethiopian economy is sensitive to climate variability, particularly variations in rainfall (Belay, unpublished). Furthermore, Climate change has an impact on health such as**;** it is a cause of encroachment of malaria from lower altitudes in Somalia and Afar regions to higher altitudes in Tigray and Amhara (NAPA web site: http://siteresources.worldbank.org).

Characterize temperature and rainfall condition is fundamental, especially countries their economy highly depends on natural rainfall. For example, Woldeamlak and Conway (2007), describes that, Ethiopian agriculture is heavily dependent on natural rainfall, with irrigation agriculture accounting for only around 1.1% of the total cultivated land in the country.

Unfortunately, rainfall predictions for Ethiopia vary hugely between climate models and for different seasons. For instance in the north, one climate model predicts a doubling of precipitation during the main rainy season, whilst another predicts a decline. However, all models predict an increase in rainfall during the dry season (October-January) (NMSA, 2001). Economic growth in Ethiopia appears highly correlated with rainfall suggesting significant potential for climate change to impact on livelihoods (Black *et al*., 2008).

The temperature has positive and negative influence on the plants and animals, such as; high temperature can be a problem, particularly to small seedlings in June and July. Applying mulch can reduce the soil temperature by 2^{o}c or more (Stern *et al.,* 2006). Another study indicated that, higher probability of temperature values exceeding the optimum requirement of crops can impair yield formation by damaging photosynthetic capacity, enzyme activity and through increased respiratory loses of assimilates (Kim *et al.,* 2007). According to (Muchow *et al.,* 1990), higher temperature values are critical climate variables that reduce the growth duration, light absorption and grain yields of crops in warmer sub-tropical region.

Climate change has been a global issue of concern for many scientists so far and we believed that climate change is sure to occur. However the magnitude and vulnerability vary in time and for all spatial scales. Ethiopia as a country; information about climate variability is so crucial; hence different studies have been done so far in different disciplines. Moreover climate change is a change in the mean climate of a certain period doesn’t give more attention on the climate variability and extremes. Climate variability and extremes affect the day to day life of the people rather than the change that will probably occur in the future. So that the main concern of this paper is to analyze and characterize the variability and extremes of Western Amhara rainfall and temperature.

The issue of climate change and variability has become more threatening not only to food security and sustainable development of any nation, but also to the totality of human existence (Gadgil *et al*., 1998). There is a substantial concern over the global problem of climate change and it is described as the most universal and irreversible environmental problem facing the planet Earth (IPCC, 2001a). The effects of climate variability such as rising temperature and changes in precipitation are undeniably clear with impacts already affecting ecosystems, biodiversity and people. These conditions determine the carrying capacity of the biosphere (IPCC, 2001a).

There are a number of factors that contribute to changes in the Earth's climate over various time scales. These include natural factors such as changes in solar output, changes in the earth's orbit and the natural greenhouse effect and anthropogenic factors. It is the climate change which is due to anthropogenic reason that is likely to be aggravating the climate change impacts particularly in many parts of Eastern Africa (IPCC, 2007).

Climate change is a global problem, but it has national, regional and local manifestations which need to be addressed. Ethiopia is one of the most vulnerable countries to the impacts of climate change. Climate change threat is greater in Ethiopia because of the country’s less adaptive capacity and deepened poverty (Michael, 2006). The negative impacts associated with climate change are also confounded by many factors, including widespread poverty, human diseases, and high population density, which is estimated to double the demand for food, water and livestock forage within the next 30 years (Davidson *et al*., 2003).

The seasonal climate variability of Ethiopia, particularly rainfall, is influenced by weather systems of various scales; from meso-scales to the large scale, mainly El Nino-Southern Oscillation (ENSO) related phenomena (NMSA, 1996). It has been also noted that the rainfall is highly variable in amount, distribution and becomes unpredictable across regions and seasons (Tesfaye and walker, 2004; Tilahun, 1999; Mersha, 1999). This variability of rainfall and recurrent droughts in Ethiopia affects the lives of millions of people as livelihood of the people depends on rainfall. In spite of these experiences, as a country whose economy is heavily dependent on rainfall and its pattern, characterizing regional/local climate parameters (temperature and rainfall trends) are often cited as one of the more important factors in explaining various socioeconomic problems.

Indisputably, rainfall and temperature are very crucial for the survival of life. Particularly, Temperature is a critical determinant of plant and animal growth. For all organisms, we can determine upper and lower lethal temperatures, in addition to upper and lower critical temperatures. These critical temperatures are those limits that cause distinct, through sub-lethal responses. For example, anther sterility in wheat at temperature above 28 °C, tomato fruit shedding at temperatures below 5 °C, or cessation of feeding in sheep above 38 °C (Stern *et al.,* 2006). Between these limits, temperature conditions are often viewed as favorable and little consideration is given to temperature alone, particularly in tropical areas where the temperature rarely changes markedly. However, temperature analysis can be important in many situations where crops, livestock, stored products, pests and diseases are all affected by the temperature conditions.

However, the detail spatial and temporal variability of the climate parameters over the country in general and Western Amhara in particular is highly complex and not well known yet. It is, therefore, essential to assess the temporal and spatial variability of rainfall and temperature in an area so as to quantify its effects on the socioeconomic activities that could be translated into the best adaptation options according to the development potential and specific challenges.

Furthermore, In Ethiopia in general and in Amhara region in particular, the risks of variability in climate patterns that smallholders face is believed to be due to the lack of regional/local climatic information, low adaptive capacity and limited adaptation options (Yesuf *et al.,* 2008). To that end, analyzing and charactering variability of rainfall and temperature through scientific investigations is crucial in order to help researchers, policymakers and developers to make more informed decisions, at regional and/or local levels. Therefore the objectives of this study are to analyze spatial and temporal temperature and rainfall variability in western Amhara for the period 1979-2008, to assess temperature and rain fall condition of Western Amhara for the period 1979-2008 and to identify the possible climate variability and extremes in Western Amhara for the period 1979-2008.

RESEARCH METHODOLOGY AND MATERIALS

Description of the Study Area

The Amhara region is located between 8°45'N and 13°45' N latitude and 35° 46' and 40° 25' E longitude. The total area of the region is estimated at 156,960 km^2 (CSA, 2005). The climatic condition of Amhara region, based on altitude, is categorized into: *Kola* (hot zone) - below 1500 m.a.s.l, and it covers 31% of the region, *Woyina Dega* (warm zone) - between 1500-2500 m.a.s.l covering 44% and *Dega* (cold zone) - between 2500-4620 m.a.s.l and it covers 25% of the region.

The mean annual temperature of the region is between 15 °C and 21 °C. But in the valleys and marginal areas the temperature exceeds 27 °C. This research was proposed to investigate spatial and temporal variability of temperature and rainfall in Western Amhara for the period of 1979-2008.

Economic activity

Economically, Agriculture in the region remains to be the dominant economic sector. Structurally, on the average it accounts for 55.8 per cent of the regional GDP and 88.7 per cent of the population derives its livelihoods from agriculture and allied activities (BoFED, 2001). It is the major source of food, raw materials for local industries, and export earnings. The fact that the region is endowed with diverse agro-ecology, different species of fauna and flora are found.

Population

The population of the region accounts for roughly 25.5 percent of the total population of the country while in terms of area; the region contributes only 15.4 percent (BoFED, 2001; CSA, 2005). Hence, if the current trend in population growth continues, the population size of the region would double within 25 years. Regarding the settlement pattern, the overwhelming majority, i.e. nearly 89 per cent of the population, resides in rural areas and is engaged mainly in agriculture. The highlands are densely populated than the lowlands. When we look into the age structure of the population, 80.6 percent are under 14 and those who are or greater than 65 constitute 6.2 percent of the population. Hence, the age dependency ratio is as high as 86.8 per cent. This simply shows that for every person, there is an addition of another one person to bear the socioeconomic burden.

Topography

The topographical features of Amhara region represent diversified elevations ranging from 700 meters above sea level (m.a.s.l.) in the eastern edge to over 4600 m.a.s.l. in the northwest. Based on moisture availability and thermal zones, ten major agro-ecological zones and 18sub-zones have been identified in the region. Based on USIAD 2000 report, Most of the Amhara region is on the highland plateau and is characterized by rugged mountains, hills, plateaus, valleys and gorges. Hence, the region has varied landscapes composed of steep fault escarpments and adjoining lowland plains in the east, nearly flat plateaus and mountains in the center, and eroded landforms in the north. Most of the western part is a flat plain extending into the Sudan lowlands A little over 50 percent of the total area of the region is considered potentially arable for agricultural production activities. Currently, 60% of the total area is used for cultivation and grazing (30% each), 17% is under forests, woodlands and shrub lands, 4% is covered by water bodies, 3% is occupied by settlements and 16% is a wasteland (Luke *et al*., 2000).

Table 1. Description of the study meteorological stations

Zone	Station	Latitude	Longitude	Altitude m.a.s.l	Database available	
					Rainfall	Temp.
WG	Bahir Dar	11°36'	37°23'	1840	1979-2011	1979-2008
EG	Debre Markos	10°20'	37°43'	2446	1979-2008	1979-2008
EG	Motta	11°5'	37°5'	2487	1979-2008	1984-2008
EG	Yetmen	10°32'	38°47'	2418	1979-2008	1980-2008
Awi	Dangla	10°16'	36°56'	2137	1979-2008	1979-2008

WG: West Gojjam, EG: East Gojjam

Source: CSA, 2005

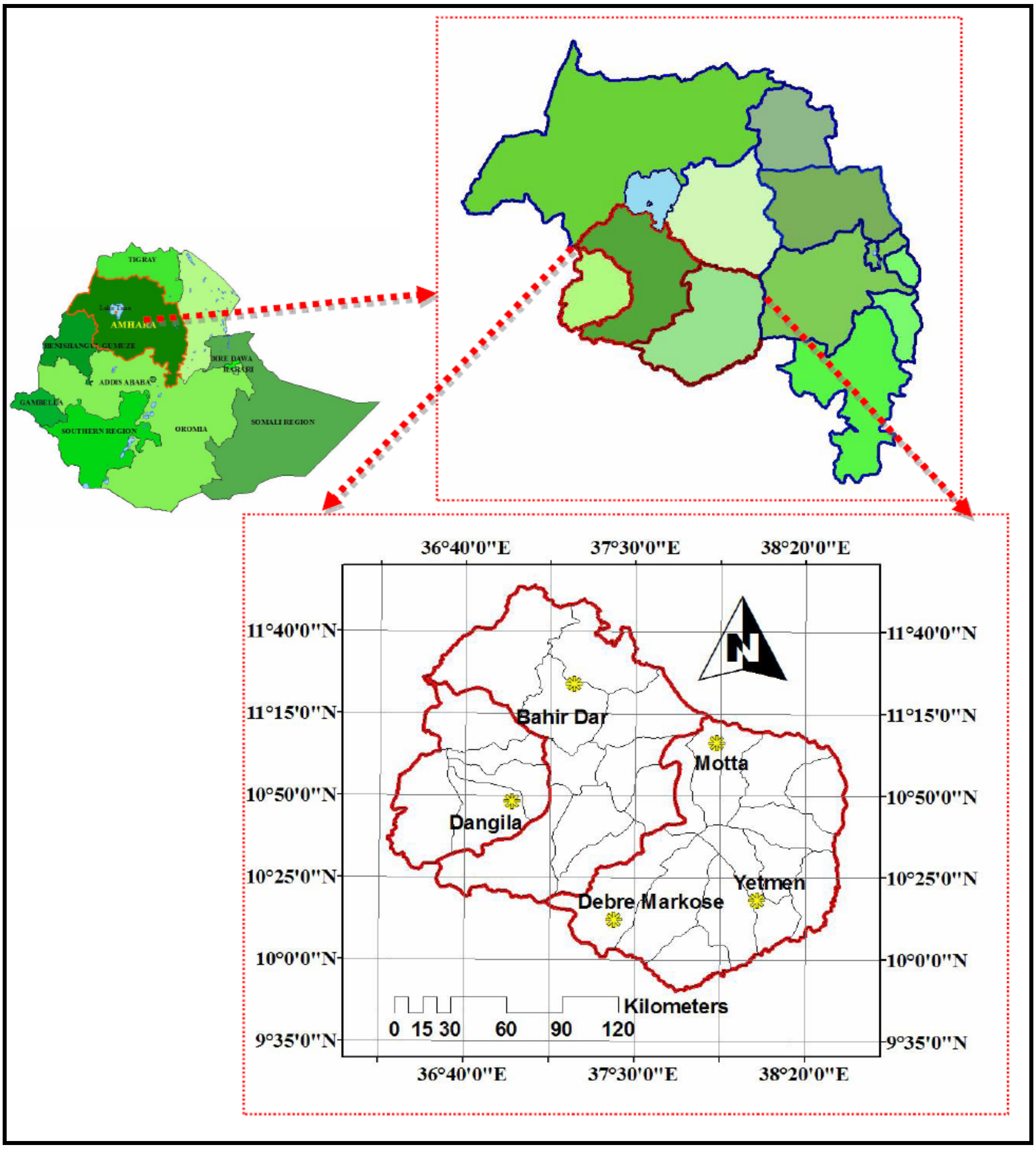


Figure 1. Map of the study meteorological stations.

Research Design and Methodology

Research Type

The type of the research is both qualitative and quantitative. The data was described and summarized quantitatively and qualitatively, which was collected from the National Meteorological Service Agency (NMSA).

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.

Data Collection Techniques

The Long term (30 years) records of daily rainfall, maximum and minimum temperature data used for the study were collected from the National Meteorological Services Agency (NMSA) of Ethiopia and/or from the archive of its branch offices found in Bahir Dar to show the spatial and temporal variability of rainfall and temperature of western Amhara. To make ready for analysis the row data series of meteorological stations should be stack. To do this the row (Daily rainfall, minimum and maximum temperature) data series was entered to Ms-excel 2003, following day of a year entry format (along columns dates of the year and rows years of data observation), and stack using INSTAT soft ware. To stack successfully number of days of the month must be adjusted, because each month has not equal number of days, based on Gregorian calendar. In addition the empty space must be filled. Otherwise it results incomplete number of day of the year. After this process the data were ready to simulation (Appendix A&B).

Missing data

Missing data is one of the main problems which are often encountered in meteorological analysis, which may be due to the absence of observer, short interruptions in observations due to a large number of causes, the most frequent problem is, the breakage or malfunction of instruments during a certain time period. When data are missing, it may be appropriate to complete these data sets from observations made in another nearby and reliable stations. So, an attempt was made in estimating missing data for study station with no complete rainfall, minimum and maximum temperature data series. There are various methods for estimation of missing data. These are: arithmetic average method, simulation of daily data from the existing by using INSTAT software and Normal Ratio method. In this study, there were missing data in daily rainfall, minimum and maximum temperature data series for each station. Regarding with missed data series the most problematic areas were: Dangla (10yrs minimum and maximum temperature and 9 years rainfall) and Yetmen (8 years minimum and 4 years maximum temperature) missing data series during observation year (1979-2008). The missed data have been estimated by using Markov chain simulation model of INSTAT (Stern *et al.*, 2006). The main reason to choose the first order to fill the missing daily rainfall, minimum and maximum temperature data is that first order doesn`t exaggerate the result and more over it give a more accurate model to each region of the study area that has been explained by NMSA (1996 b).

Data analysis

The appropriate rainfall, minimum and maximum temperature data were captured into Microsoft Excel, 2003 spreadsheet following the days of a year (DOY) entry format. Data quality control was done by careful inspection of the completeness, spatial and temporal consistency of the rainfall records in the study areas. Daily rainfall and temperature data sets were subjected to detailed analyses using sequences of statistical packages. All records are analyzed and the missing data calculated and simulated by using INSTAT+v. 3.36 first or second order Markov-chain simulation models (Stern *et al.,* 2006). The outset, the Box and Whiskers plotting technique was used to illustrate the inter-annual spread of the rainfall series with respect to onset date, end date and duration of the main season rainfall. In addition seasonal rainfall variability of the study stations was analyzed and mapped using Arc GIS 3.2 software. Coefficient of variation (CV) was calculated as the ratio of standard deviation to the mean (NMSA, 1996) and in order to study the monthly variability of rainfall in the study area, a modified version of (Oliver, 1980) Precipitation Concentration Index (PCI) was used. This index described as:

$$PCI=100 \times [\Sigma Pi^2 / (\Sigma Pi)^2$$

Where: Pi is the rainfall amount of the i^{th}month; and Σ is summation over the 12 months

PCI values of less than 10 indicate uniform monthly distribution of rainfall, values between 11 and 20 indicate high concentration, and values above 21 indicate very high concentration (Oliver, 1980). Further, as indicated in Agnew and Chappel (1999) the standardized rainfall anomalies were calculated and graphically presented to evaluate inter annual fluctuations of rainfall in the study area over the period of observation, described as:

$$SRA= (Pt-Pm) /\sigma$$

Where: SRA is standardized rainfall anomaly, Pt is an annual rainfall in year t,

Pm is long term mean annual rainfall over a period of observation and

σ is the standard deviation of annual rainfall over the period of observation.

The drought severity classes are extreme drought (SRA< -1.65), severe drought (-1.28>SRA>-1.65), moderate drought (-0.84>SRA>-1.28), and no drought (SRA>-0.84). Average monthly minimum and maximum, mean and extreme temperature pattern of the study area with time series analysis was made. In addition the graphical presentation was prepared by using INSTAT+v. 3.36 first order Markov-chain simulation models (Stern *et al.,* 2006). To test the trends of rainfall and temperature Spearman`s rank-correlation method was used. The Spearman`s rho test, the areal rainfall, minimum and maximum temperature trends obtained using Nicholson (1985), were analyzed using INSTAT+v3. 36 software

$$R_{sp} = 1 - \frac{6 * \sum_{i=1}^{n} (D_i * D_i)}{n * (n * n - 1)}$$

Where n is total number of data, D is difference, and i is the chronological order number.

Di=Kxi-Kyi

Where Kxi is the rank of the variable, x, which is the chronological order number of the observations, Kyi is the chronological order number of an observation in the original series

$$t_t = R_{sp} \left[\frac{n-2}{1 - R_{sp} * R_{sp}} \right]^{0.5}$$

Where t_t is calculated value

RESULTS AND DISCUSSIONS

This section presents a detailed description of the results obtained from the analyses that have an effect on the temporal and spatial rainfall and temperature variability over western Amhara. To show temporal and spatial variability of rainfall and temperature, it is recommended to use 30 years and above observed data (Bahir Dar, 1979-2011; Motta, Yetmen, Debre Markos, and Dangla, 1979-2008). This research focuses on characterization of rainfall and temperature variations of western Amhara. Because most farmers live in this area practice rain fed agricultural activities.

1. Rainfall Features

1.1 Onset dates, End dates and duration of Rainfall

Provide information about the distribution, onset date, end date and duration of rainfall is so crucial, particularly areas their activities dependent on rainfall. The rainfall pattern in the study area exhibits a monomodal nature (long rain during kiremt season). To characterize an onset date of the past records, many different criteria exist for different crops exhibiting different maturity, drought tolerance level and soil type. Here, the one with 20mm of total rainfall received over three consecutive days that were not followed by greater than ten days of dry spell length within 30 days from planting was adopted (Raman, 1974) as a rainy season.

The main rainy season of the study area is summer, i.e. June, July, August and September. The following figure shows that the variability of the onset dates of rainfall in each study station. The mean onset date of Bahir Dar, Motta, Yetmen, Debre Markos and Dangla was; 153,151, 151, 144 and 132 DOY (Day of the year starting from January first), respectively. In addition it has temporal variation: Such as an onset date of Bahir Dar, Motta, Yetmen, and Dangla in 1979 was slightly similar, that was 129 (May 8), 128 (May 7), 125 (May 4) and 122 (May 1) DOY, respectively. It was too early, where in the next year in Bahir Dar and Motta, it was too late, i.e. 177 (June 26) and 181 (June 29) DOY, respectively. Yetmen and Dangla remains the same. On the other hand the onset date of Debre Markos in 1979 was 164 DOY (June12), it was too late, but in the next year it became too early. The analysis of onset date indicated that variation through all observation years in all study areas (see appendix D).

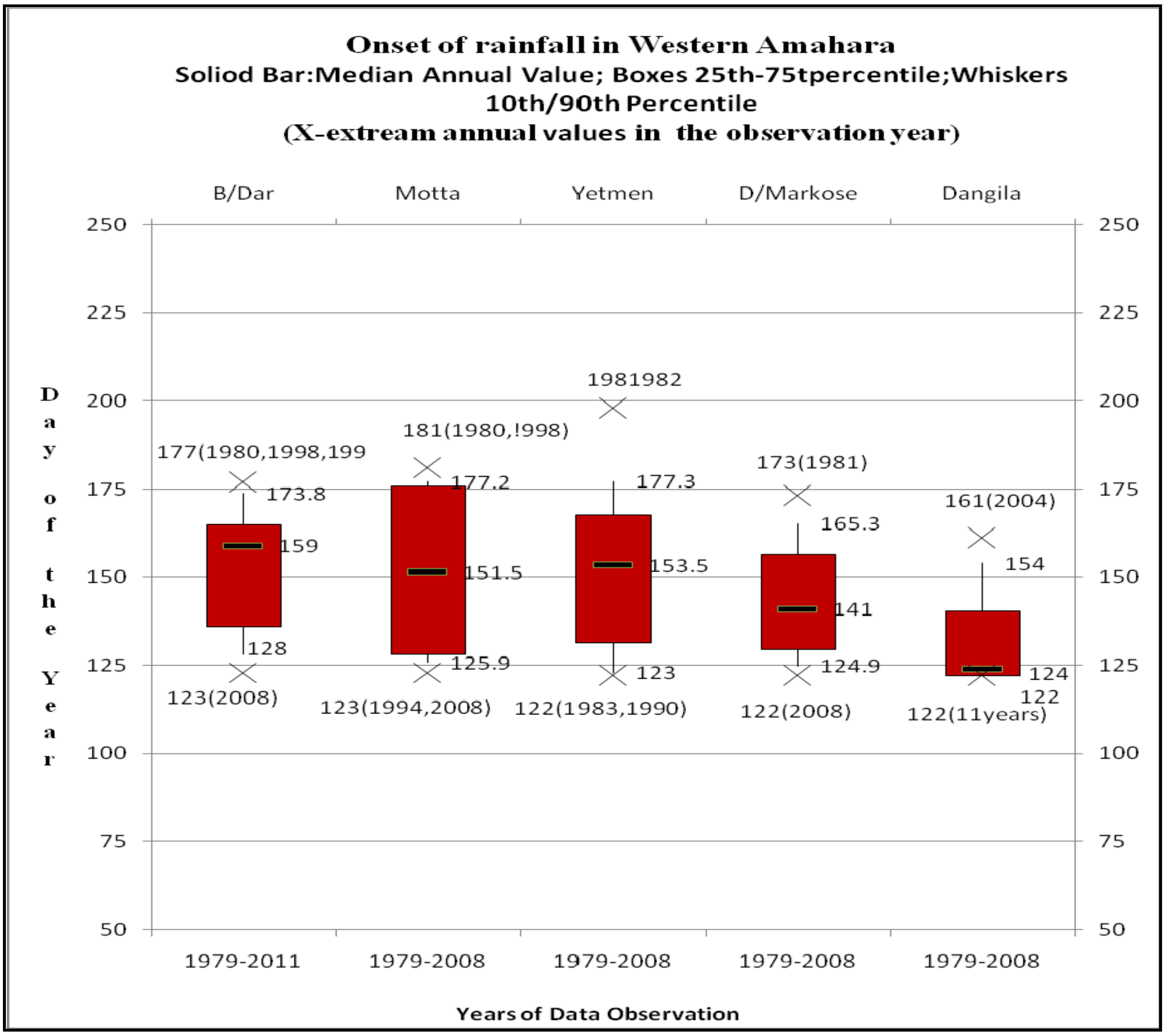


Figure 2. Box and Whisker Plots of the onset dates of Rainfall for kiremt (June to September) season rainfall in Western Amhara.

The end of the growing season is mainly dictated by the stored soil water and its availability to the crop after the rain stops. In this study the end of the rainy season was defined as any day after the first of September, the soil water reaches zero (stern *et al.*, 1982). Hence, the average end date of Bahir Dar, Motta, Yetmen, Debre Markos and Dangla was; 302, 304, 292, 302 and 317 DOY, respectively. The end date of rainfall ranged from 257 DOY (September 13) at Yetmen during 2006 to 354 DOY (December 19) at Motta during 1998 (Figure 3). 1997 has maximum end dates of rainfall in almost all study stations.

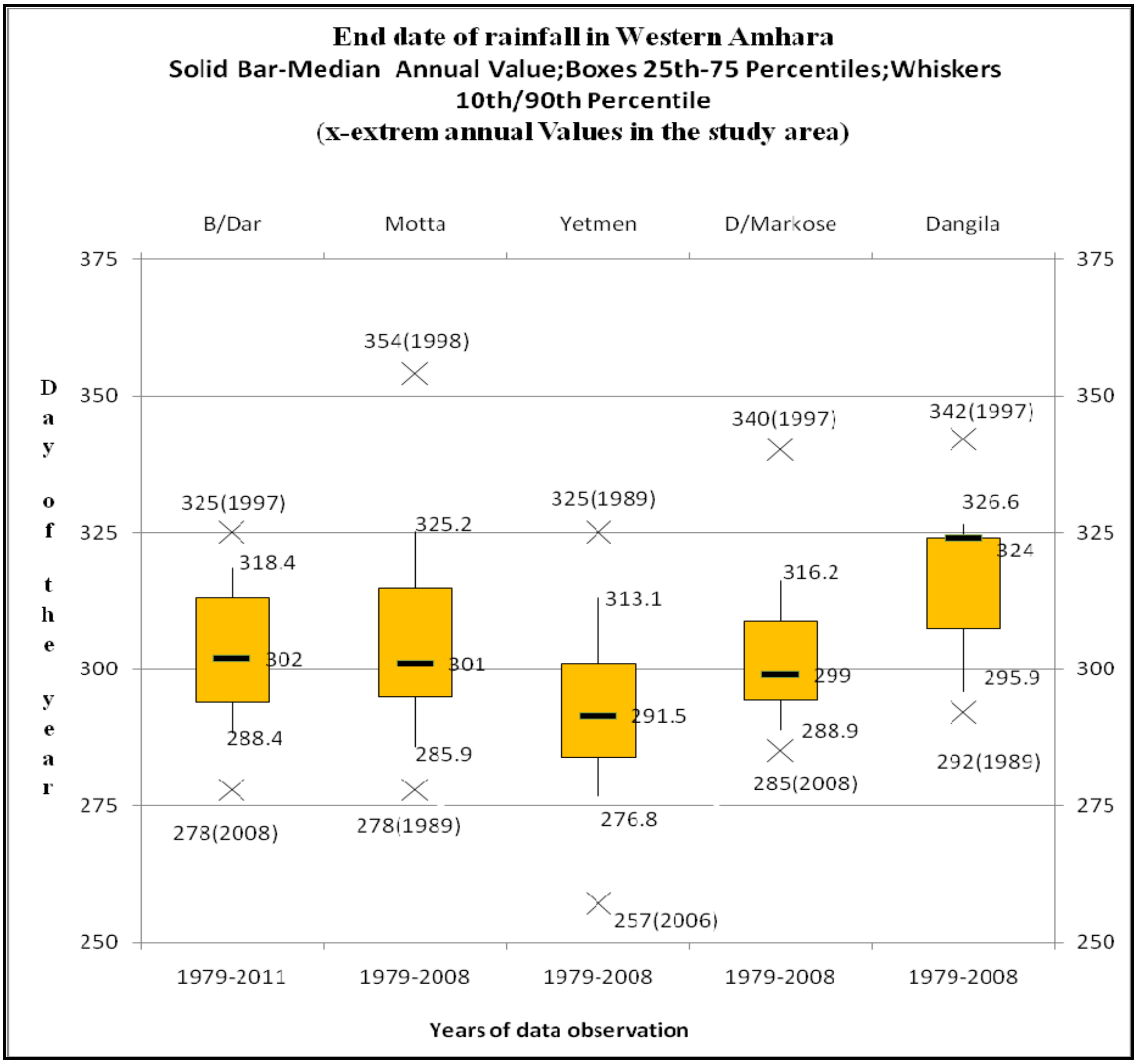


Figure 3. Box and Whisker Plots of the end dates of Rainfall for kiremt (June to September) season rainfall in Western Amhara.

The Mean Rainfall duration of Bahir Dar, Motta, Yetmen, Debre Markos and Dangla is 149,153,142,158 and 185 days respectively. All areas have long duration of rainfall. The range of rainfall duration was in between 98 DOY at Yetmen (1998) to 214 DOY at Dangla (1997) see figure 4. Similar to end dates of the rainfall, 1997 recorded maximum duration of rainfall.

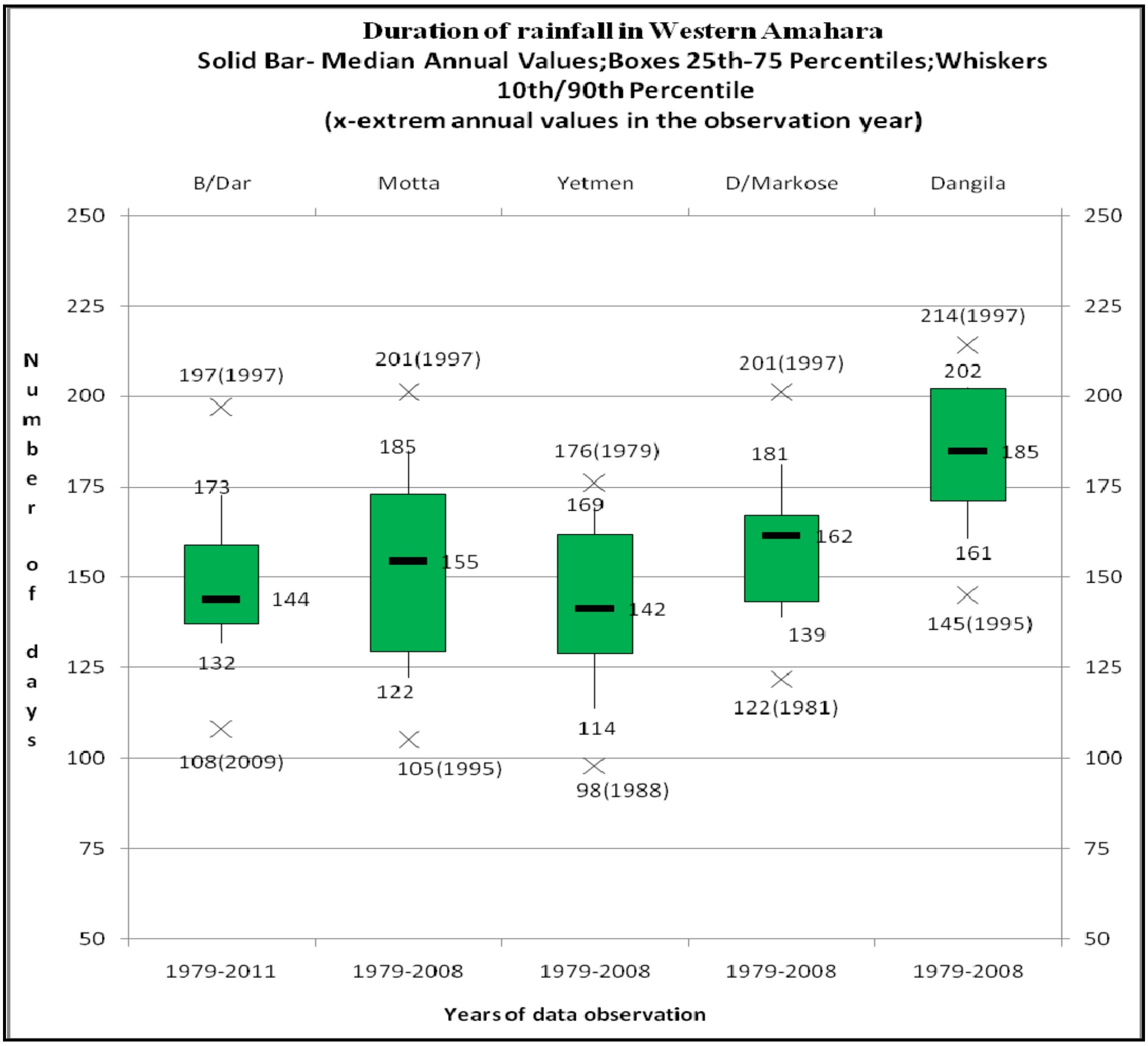


Figure 4. Box and Whisker Plots of duration of Rainfall for kiremt (June to September) season in Western Amhara.

Generally, the main problem of Western Amhara was not duration of kiremt rainfall. Instead it is a result of fluctuation of onset dates and end dates (delay of the starting dates and early cessation) of rain relatively to previous year.

1.2 Annual patterns of rainfall

The annual total rainfall of Western Amahara varies temporally and spatially, ranged from 878mm to 2100mm both recorded in Yetmen (Appendix: C). Western Amhara received mean annual rainfall of 1368.78mm per year. All study stations experienced mean annual rainfall amounts of >1000mm. Motta experienced mean annual rainfall of 1194.6mm in the period of observation, with a standard deviation of 184.29mm and 15% coefficient variation.

At the same time as Dangla received 1653mm rainfall per year, 187.16mm standard deviation and 11% of coefficient variation. The variation has been higher in Yetmen relative with another station (Table 3). The findings of Dereje *et al.* (2012) and Woldeamlak and Conway (2007), reveal that the Amhara National Regional State receives much of the rainfall in June, July, August and September. Likewise the contribution of kiremt rainfall to an annual total in western Amhara is high. Precipitation Concentration Index (PCI) value indicates that western Amhara is characterized by high to very high monthly rainfall concentration (Table 2).

1.3 Kiremt Season Rainfall

Western Amhara heavily experienced high rainfall during June, July, August and September. According to Seleshi and Zanke (2004), the kiremt season starts in July, lasts for about three-four months as a result of convergence in low-pressure systems, and the Inter Tropical Convergence Zone (ITCZ). This season contributes 77.05% of the mean annual rainfall of western Amhara (Table 2). The mean annual rainfall of kiremt season in western Amhara was 1054.2mm (Table 3). The contribution of the Bahir Dar station to the total annual rainfall was very high i.e. 84.7% followed by Dangla (76.5%). Whereas relatively minimum contribution of kiremt rainfall to annual total was recorded at Debre Markose (Table 2).

1.4 Belg season Rainfall

From the present study it was possible to note that, Belg (March, April and May) rainfall has not a significant contribution to the annual total (Table 2) in west Amhara, during the period. The remaining months these are, October, November, December, January and February have taken as Bega season.

Table 2. Average contribution of the three seasons to the annual average and the precipitation index (in percent), 1979-2008

Station	Kiremt Rainfall	Belg Rainfall	Bega Rainfall	PCI (%)
Bahir Dar	84.7	7.8	7.5	20.9
Motta	75.0	12.6	12.4	16.7
Yetmen	76.3	16.5	7.2	17.0
Debre Markos	72.6	16.6	10.8	15.2
Dangla	76.5	13.0	10.5	16.5

However the amount of Belg rainfall was not considerable, Debre Markos received the maximum mean Belg rainfall followed by Dangla (Table 3).

Generally, Western Amhara annual total rainfall shows moderate spatial and seasonal variability. The coefficient variation indicates that Belg and Bega season rainfall of Western Amhara was highly variable than Kiremt rainfall in which the coefficient variation is low during study periods (Table 3). This is supported by Dereje *et al.* (2012) in their study that analyzed 10 stations in the Amhara Region and noted that the Belg and the Bega rainfalls are found much more variation (>30%) than the kiremt rainfall in which the coefficient of variation is lower than >30%.

Table 3. Annual and Seasonal mean of rainfall, standard deviation (mm) and coefficient of variation (in percent), 1978-2008

Station	Annual			Kiremt			Belg			Bega		
	Mean	CV	SD	Mean	CV	SD	Mean	CV	SD	Mean	CV	SD
Bahir Dar	1353	0.13	173	1147	0.16	178	105	0.64	69	101	0.59	60
Motta	1195	0.15	184	897	0.16	140	150	0.47	71	149	0.63	94
Yetmen	1301	0.19	242	990	0.20	200	215	0.42	91	93	0.84	78
D/ Markos	1342	0.11	145	974	0.11	103	223	0.39	86	145	0.56	80
Dangla	1653	0.11	187	1264	0.11	134	216	0.39	83	174	0.43	75

1.5 Inter Annual Fluctuation of Rainfall

The time series analysis of total annual rainfall was done to reveal the general trends of rainfall amounts over the study area. The result of standardized rainfall anomalies indicated that the inter annual variability of rainfall and (the following figures) shows lack of annual total rainfall trends for the period from 1979 to 2008 at Motta, Yetmen, Debre Markos, Dangla and (1979-2011) Bahir Dar.

Rainfall in western Amhara shows significant decadal variability, this means a year with a positive anomaly tends to be followed by another year with a positive anomaly as do years with negative anomalies. Regarding with the annual rainfall anomaly, more than 50% of the study area showed below average rainfall record while the remaining half showed above average rainfall amount.

In Bahir Dar, annual rainfall shows negative anomaly for the 1979-1988 decade, except 1981 and 1985 when a slight positive anomaly have occurred whereas positive anomalies occurred in the 1998-2008 decade, except in 2007. During the wettest year`s annual rainfall have been 2.0 times the standard deviations above the long term (1979-2011) average. On the other hand, annual rainfall was found to be 2.61 times the standard deviation below the long term average during the dry years (Figure 5).

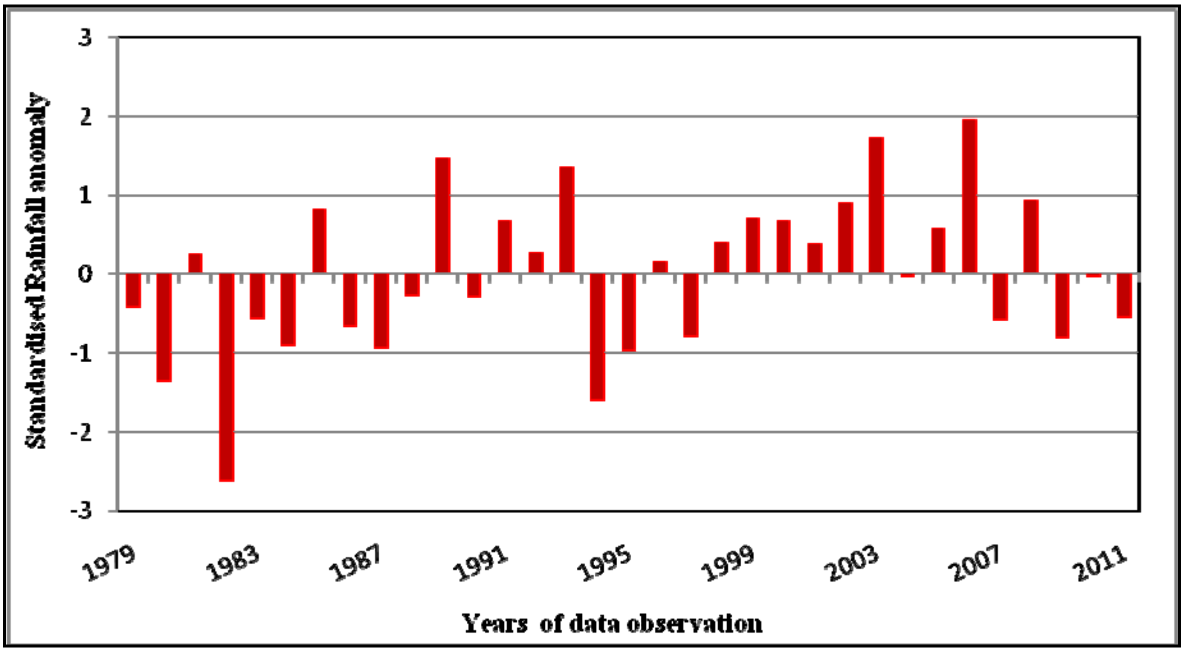
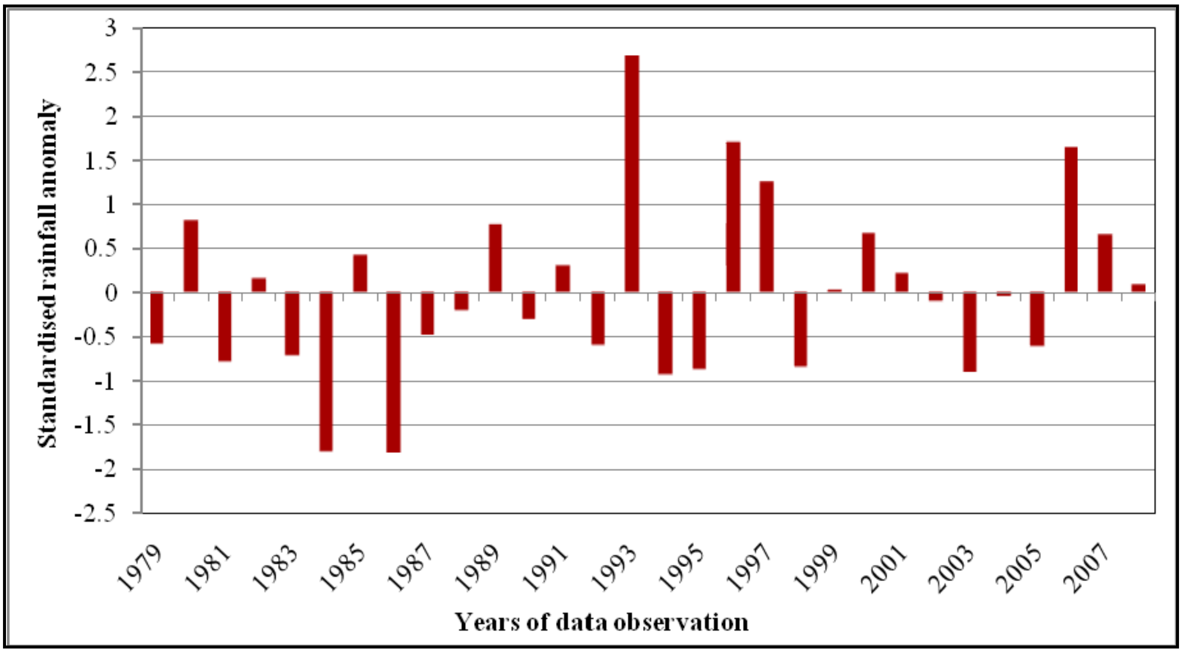


Figure 5. Standardized anomalies of annual rainfall in Bahir Dar station during the observation years (1979-2011).

Substantial positive anomalies occurred in Debre Markos during 1993, 1996 and 2006. During the wettest years, the annual rainfall was 2.68, 1.7 and 1.65 times the standard deviations above the 1979-2008 mean rainfall. The negative anomalies occurred in Debre

(a)



(b)

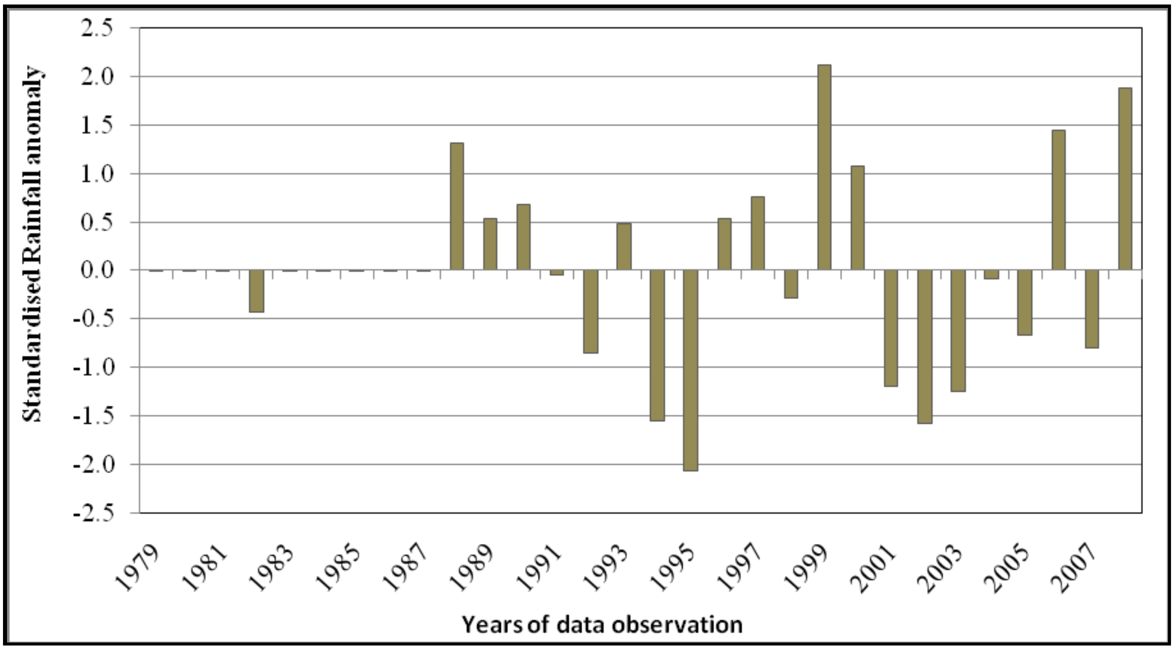
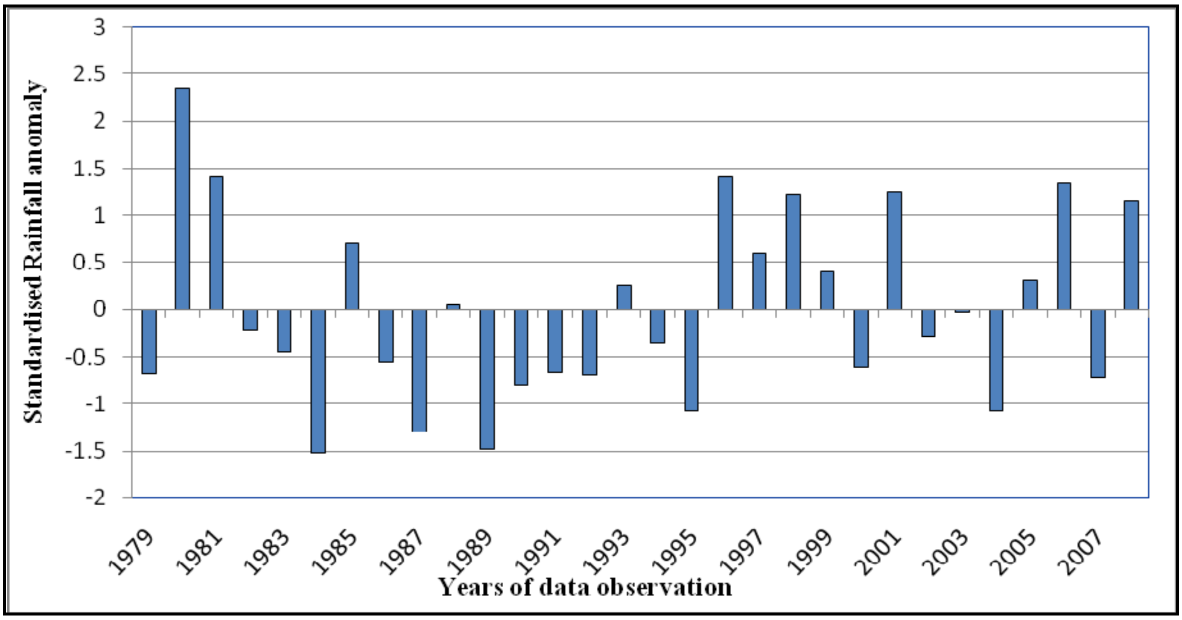


Figure 6. Standardized anomalies of annual rainfall in Debre Markos (a) and Dangla (b) station during the observation years (1979-2008).

Markos during 1980s, the driest year rainfall have been 1.8 times the standard deviation below the long term average (Figure 6a). In Dangla during 1999 and 2008 positive anomalies were occurred. Where, negative anomalies occurred during 1994, 1995, 2001, 2002 and 2003. During the wettest and driest years, annual rainfalls have been 2.35 and 2.22 times the standard deviation above and below the long-term (1979-2008) average, respectively (Figure 6b). The other considerable positive anomalies occurred at Motta and Yetmen. In Motta and Yetmen during the wettest year's annual rainfall have been 2.3 and 3.3 times the standard deviation above the long-term (1979-2008) average, respectively (Figure 7 a & b). During the driest year, before 1995 in all study station was below the 1979-2008 mean rainfall of the study area. This idea is supported by Dereje *et al.* (2012) and Woldeamlak and Conway (2007) in their study 1980s was come up with the lowest rainfall record in the study area.

(a)



(b)

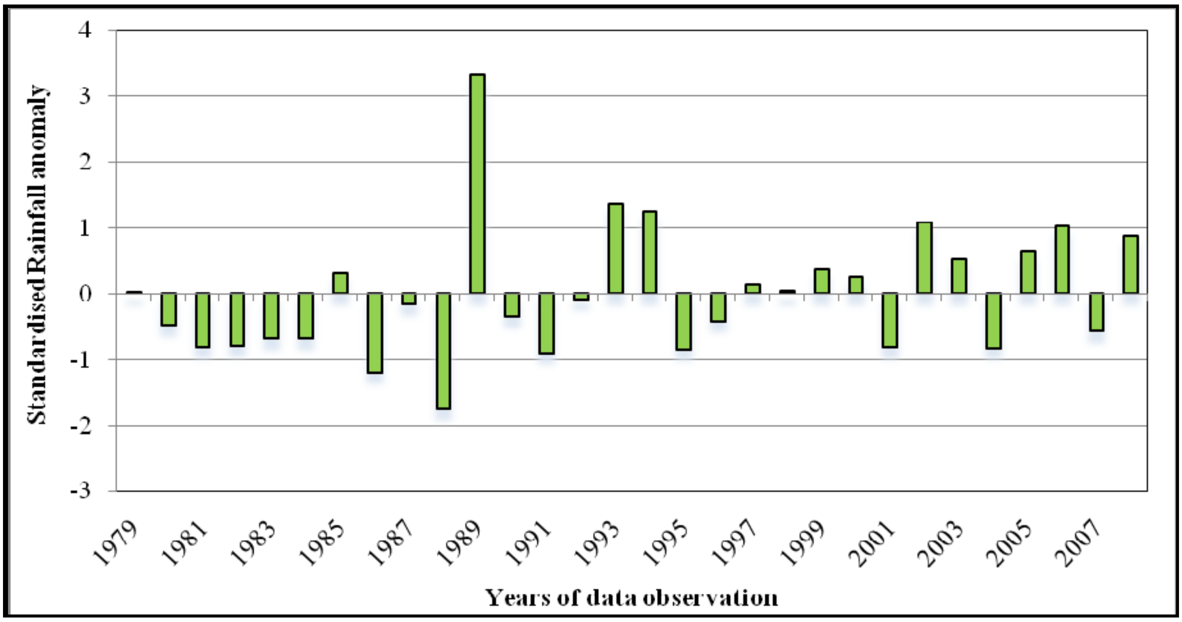


Figure 7. Standardized anomalies of annual rainfall in Mott (a) and Yetmen (b) station during observation years (1979-2008).

Generally, the time series analysis of total annual rainfall of western Amhara reveals that, the area characterized by episodic fluctuation of the wet and dry years. The overall rainfall trend in Western Amhara can be noted that increased during the observation period (1979-2008) at Bahir Dar, Debre Markos Yetmen, and Dangla. But this was not true at Motta.

As figure 8, 9 and 10 indicates that, western Amhara has annual and seasonal and spatial rainfall variation. Dangla received the maximum mean annual rainfall that was 1653mm and 187 standard deviation. At the same time Motta received relatively minimum rainfall (1195mm) during the observation period. Likewise the maximum kiremt rainfall was found at Dangla followed by Bahir Dar.

Even if, the contribution of Belg rainfall to annual mean was insignificant it shows spatial and temporal variation during the observation period. Debre Markos received the maximum Belg rainfall followed by Dangla.

In general rainfall, in western Amhara has monomodal characteristics, has moderate spatial and temporal variation. Besides it shows moderate inter-annual variation. The variation is too much for Belg rainfall than kiremt rainfall.

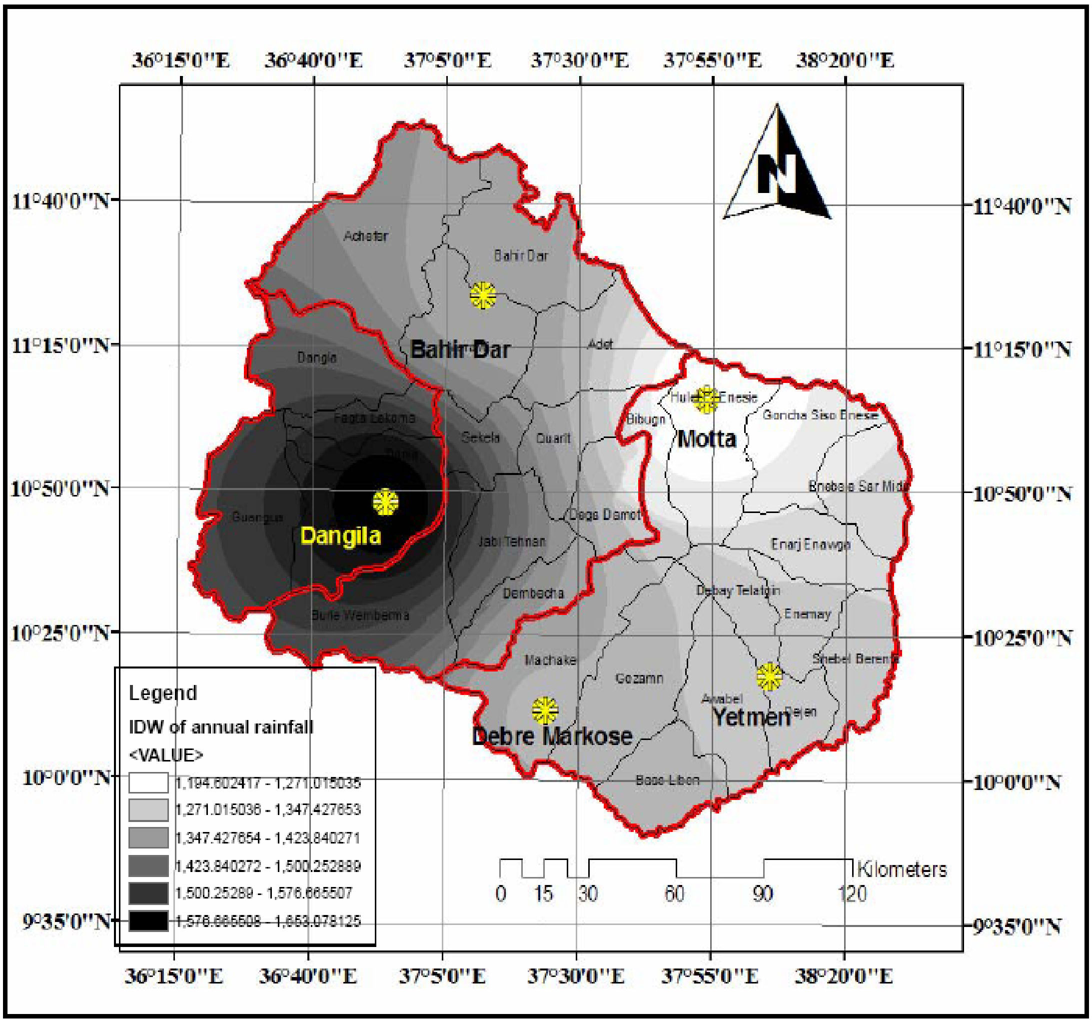


Figure 8. Image showing the spatial distribution of mean annual rainfall with their coefficient of variations over 30 years average (1979-2008) mapped using ArcGIS 9.2 software.

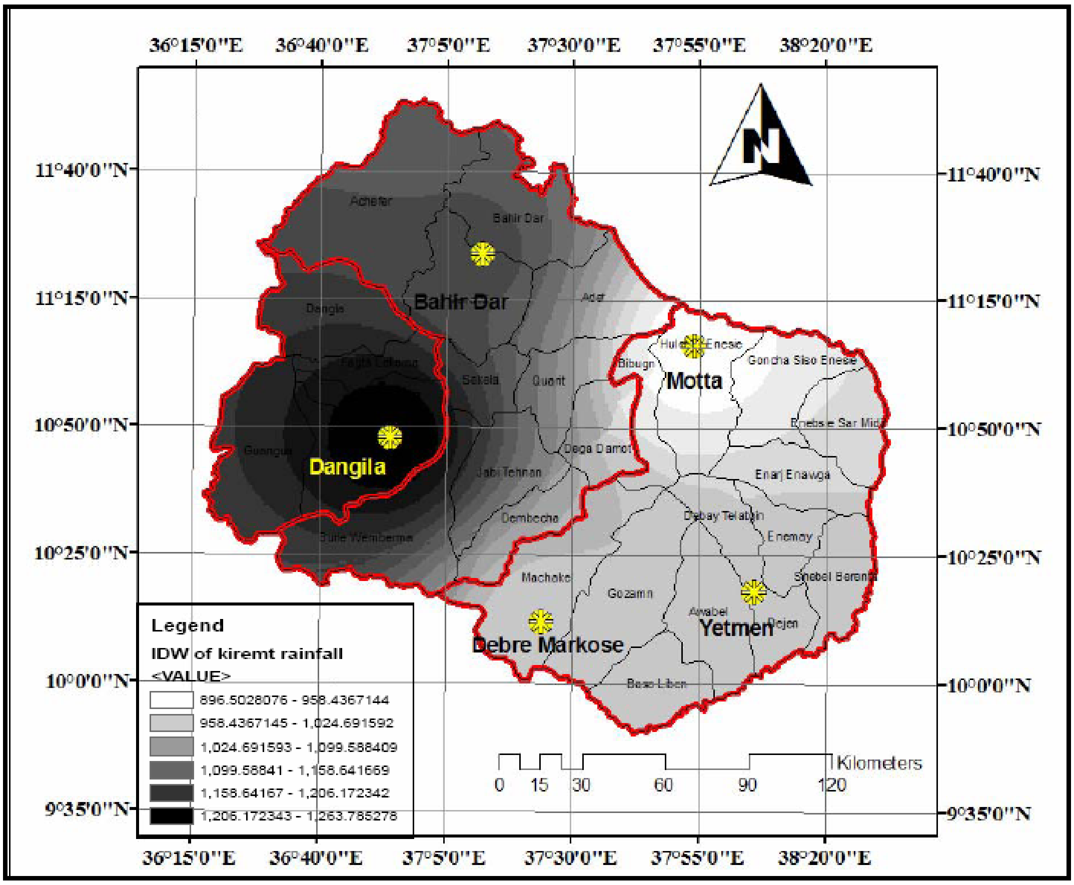


Figure 9. Image showing the spatial distribution of mean kiremt rainfall with their coefficient of variations over 30 years average (1979-2008) mapped using ArcGIS 9.2 software.

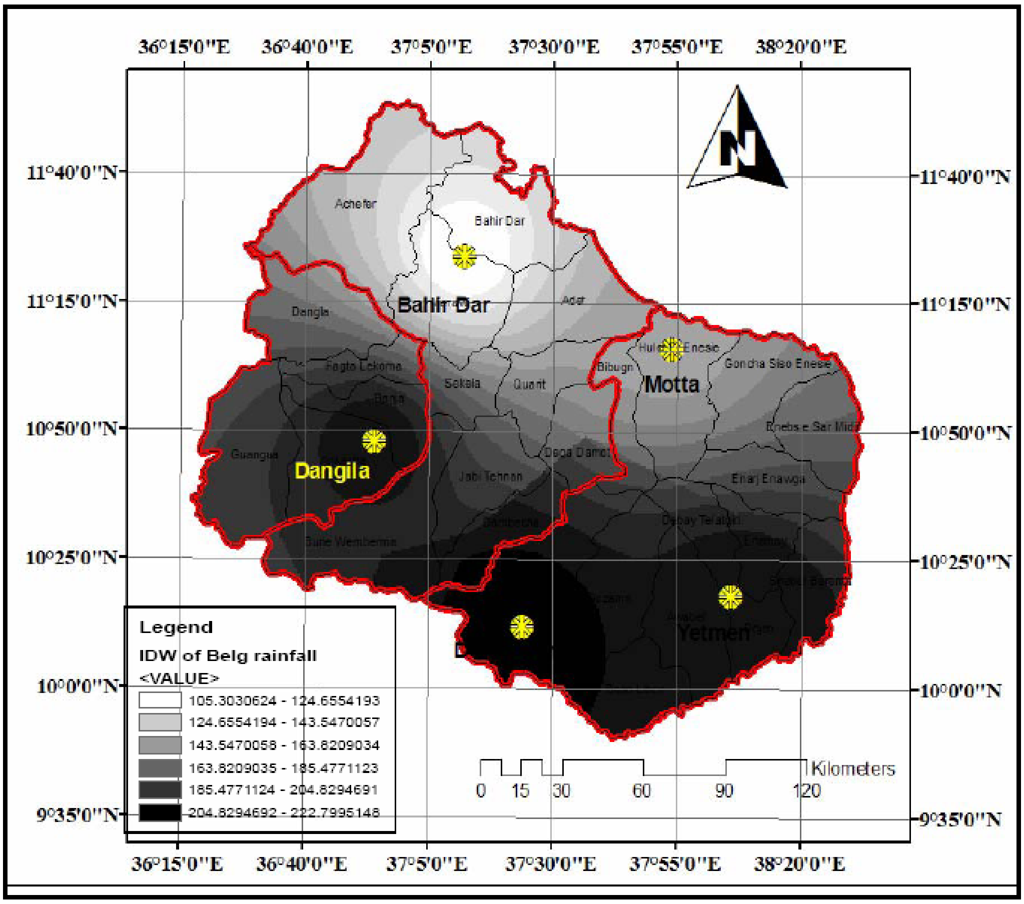


Figure 10. Image showing the spatial distribution of mean Belg rainfall with their coefficient of variations over 30 years average (1979-2008) mapped using ArcGIS 9.2 software.

1.6 Annual trends of rainfall in study meteorological station during 1979-2008

There was a significant increasing trend of annual rainfall in Bahir Dar, Yetmen and Dangla at 0.05 significant levels, during the study period (Appendix F). While there was a significant decreasing trend in Debre Markos and no significant increasing or decreasing trend in Motta during 1979-2008. From the analysis, the trend of the areal mean of Western Amhara, can be noted that there was significant increasing trend in western Amhara during 1979-2008 (Table 4).

Table 4. Annual rainfall (mm) trends in Bahir Dar (1979-2011), Motta, Yetmen, Debre Markos and Dangla (1979-2008)

Station	Slope	Spearman`s rho	t_t (calculated value)
Bahir Dar	6.3	0.69*	6.44
Motta	2.5	0.11	1.77
Yetmen	7.8	0.34*	3.26
Debre Markos	4.1	-0.09*	-2.40
Dangla	0.2	0.17*	2.24
Areal mean of western Amhara	4.9	0.34*	3.30

*Significant at 0.05 levels, critical value 2.04

2. Temperature Variability

To show Temperature variability of Western Amhara, obtained daily minimum and maximum observed data from the National Meteorology Service Agency, Motta (1984-2008), Yetmen (1980-2008), Bahir Dar, Debre Markos, and Dangla (1979-2008). Daily temperatures can be examined for the occurrence of average, low or high temperature extremes. Further characterizing and quantifying temperature data has various advantages: such as, to help make decisions about how crop are grown and managed, to estimate yields to help government and incorporate decision about buying and selling products and to improve understanding and suggest new or improved management methods.

2.1. Spatial and Temporal Maximum and Minimum Temperature Variability

The mean annual temperature of Western Amhara was in between 16.9^{o}c and 26.0^{o}c. Annual average maximum and minimum temperature of the study area reveal spatial and temporal variation. Average minimum and maximum temperature of Bahir Dar, Debre Markos and Yetmen was 11.5^{o}c, 10.4^{o}c, 10.0^{o}c and 26.9^{o}c, 22.9^{o}c, 24.7^{o}c, respectively for the period of observation. The highest average maximum temperature was recorded at Motta (32^{o}c) with 0.6 ^{o}c standard deviation, while the lowest average minimum temperature was at Dangla (9.2^{o}c) and 0.7^{o}c deviates from long term average (Table 5). The coefficient variation is much higher for minimum temperature than maximum temperature in all study station (Table 5). From the analysis we can noted that Bahir Dar was hotter than the rest station.

Table 5. Annual mean minimum temperature and annual mean maximum temperature, temperature rang and SD of temperature (^{O}C) and CV (%), 1979-2008

	Mean		Range		CV (%)		SD	
Station	MinT^{o}	MaxT^{o}	MinT^{o}	MaxT^{o}	MinT^{o}	MaxT^{o}	MinT^{o}	MaxT^{o}
Bahir Dar	11.5	26.9	11.0	1.8	0.22	0.16	2.55	0.43
Motta	12.2	32.7	8.8	2.1	0.14	0.17	1.7	0.55
Yetmen	10.0	24.7	4.2	4.4	0.80	0.35	0.79	0.85
DebreMarkos	10.4	22.9	2.5	1.7	0.48	0.20	0.49	0.45
Dangla	9.2	25.3	3.0	2.8	0.79	0.22	0.72	0.55

MinT^{o} – minimum temperature (^{O}C); MaxT^{o}- maximum temperature (^{O}C); CV- coefficient of variation (%) and SD- Standard deviation

In almost all study station the maximum temperature reaches its highest level during March, April and May but, decrease again to lowest temperature level in July, August and September. Areal average of the five stations, during the periods between 1979 and 2008, indicated that the study area has a relatively increasing trend.

2.2. Extreme high and low temperature event

Assessing the risk of temperature variability to high value fruit production in temperate or high altitude tropical localities, or planning cropping calendars for cold sensitive crops, such as rice, where temperatures below 15^{o}c affect development and below 12^{o}c cause permanent physical damage (Stern *et al.,* 2006). But the detection of trends in weather extremes remains a challenge because of the rare occurrence of extreme events. Moreover, the detection likelihood decreases with increasing rarity of the event (Frei and Schar, 2001; Klein Tank and Konnen, 2003). The occurrence and the magnitude of extreme events vary place to place and time to time, depend on latitudinal location, altitude and other factors which affect the climatic condition of an area, such as distance from the sea, ocean current etc. In the context of western Amhara the majority of minimum and maximum temperature records found in between >7^{o}c and <28^{o}c, respectively. Hence, the study takes <3^{o}c, <5^{o}c, <7^{o}c and >28^{o}c, >30^{o}c, and >32^{o}c as minimum and maximum extremes, respectively. The frequency of minimum temperature <3^{o}c was high in Yetmen and low in Debre Markos during the 1st decade of study year. While Dangla comes 1st during 2nd and 3rd decade, at the same time Debre Markos has few records. High frequency of minimum temperature <5°c and <7°c was occurred at Dangla during the observation year (Table 6).

When come to maximum temperature frequency Bahir Dar has highest records for >28°c, >30°c and >32°c during 1st, 2nd and 3rd decades. But the frequency was too high during 3rd decade for all extremes. Dangla also recorded 104 days with >30°c during 3rd decade of the study years (Table 6).

Table 6. Extreme Minimum and maximum temperature event and their frequency during 1st (1979-1988), 2nd (1989-1998), 3rd (1999-2008) decades

Events	Temperature (°C)	Year of observation (decades)	Stations				
			Bahir Dar	Debre Markos	Dangla	Motta	Yetmen
Minimum temperature	<3	1st	10	2	11	17	21
		2nd	12	0	180	15	8
		3rd	8	2	125	12	40
	<5	1st	28	24	386	99	156
		2nd	34	10	567	86	14
		3rd	36	8	449	107	65
	<7	1st	190	204	1007	280	696
		2nd	140	163	1159	454	189
		3rd	205	131	950	478	264
Maximum temperature	>28	1st	961	20	278	84	32
		2nd	1044	29	270	66	8
		3rd	1200	49	593	100	250
	>30	1st	338	1	0	5	0
		2nd	328	1	21	8	0
		3rd	520	1	104	5	17
	>32	1st	46	1	0	3	0
		2nd	38	0	0	8	0
		3rd	84	1	0	5	2

The existence and frequencies of extreme minimum and maximum temperature events has warming effect on climatic condition of the study area.

Figure 11 shows that, March, April and May were the hottest months, when all the years had at least one day with a maximum temperature of 30°c or more. The overall record high in almost 30 years was 39.5°c. August, December and January were the only months in the observation years that never had a day with a maximum temperature above 30°c. The range of temperature was in between 0.3°c at Yetmen during December and 39.9°c at Motta during May. The highest level of maximum temperature of Bahir Dar was 33.3 °c during May and its lowest level was 23.9°c.

The highest level of minimum temperature at Bahir Dar recorded during June (i.e. 17.9°c) and lowest level of minimum temperature was 4.9°c during January. Similarly Dangla recorded a maximum temperature during May that was 30.6°c and lowest minimum temperature 2.2°c during December.

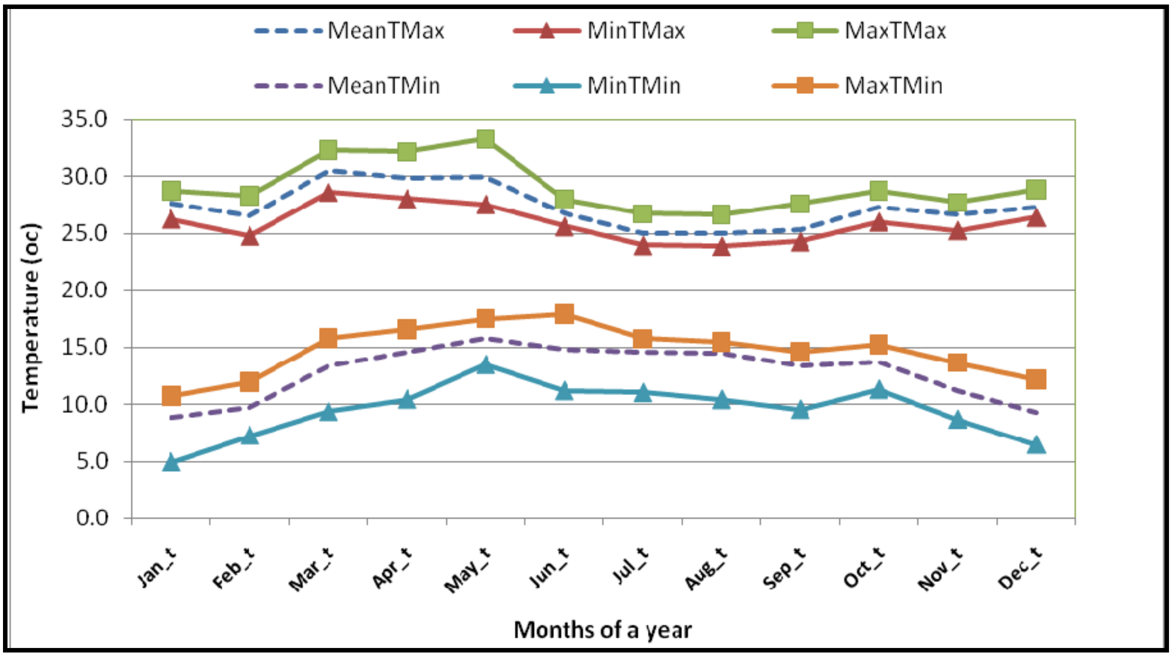


Figure 11. Average minimum and average maximum temperature pattern by month at Bahir Dar (1979-2008)

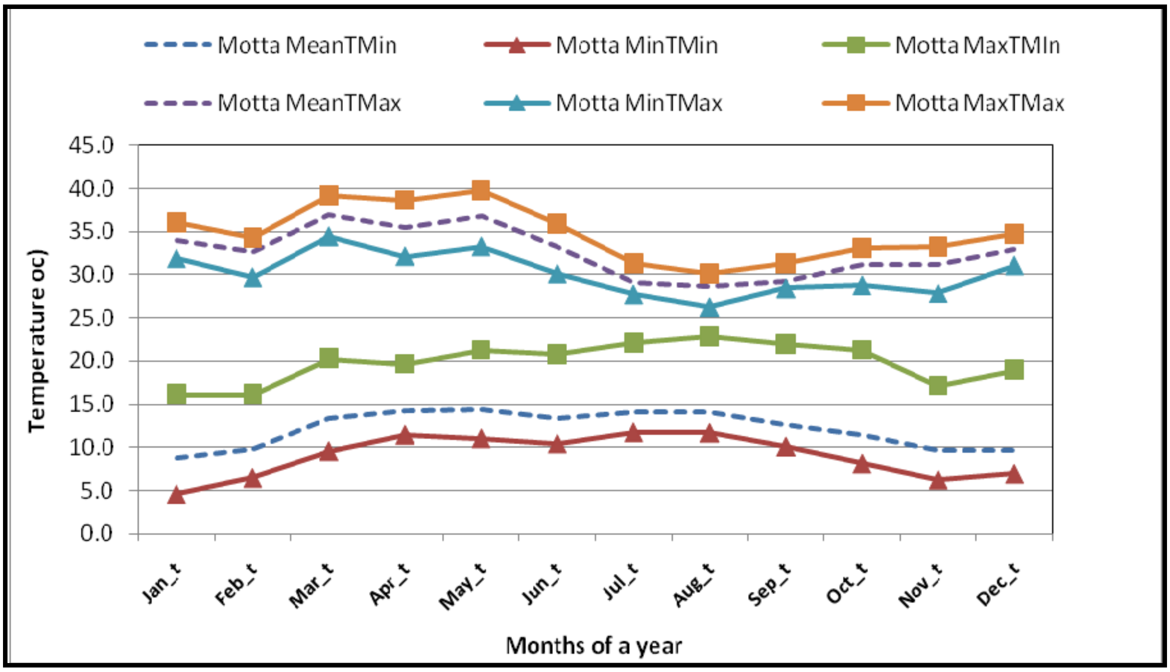


Figure 12. Average minimum and average maximum temperature pattern by month at Motta (1984-2008).

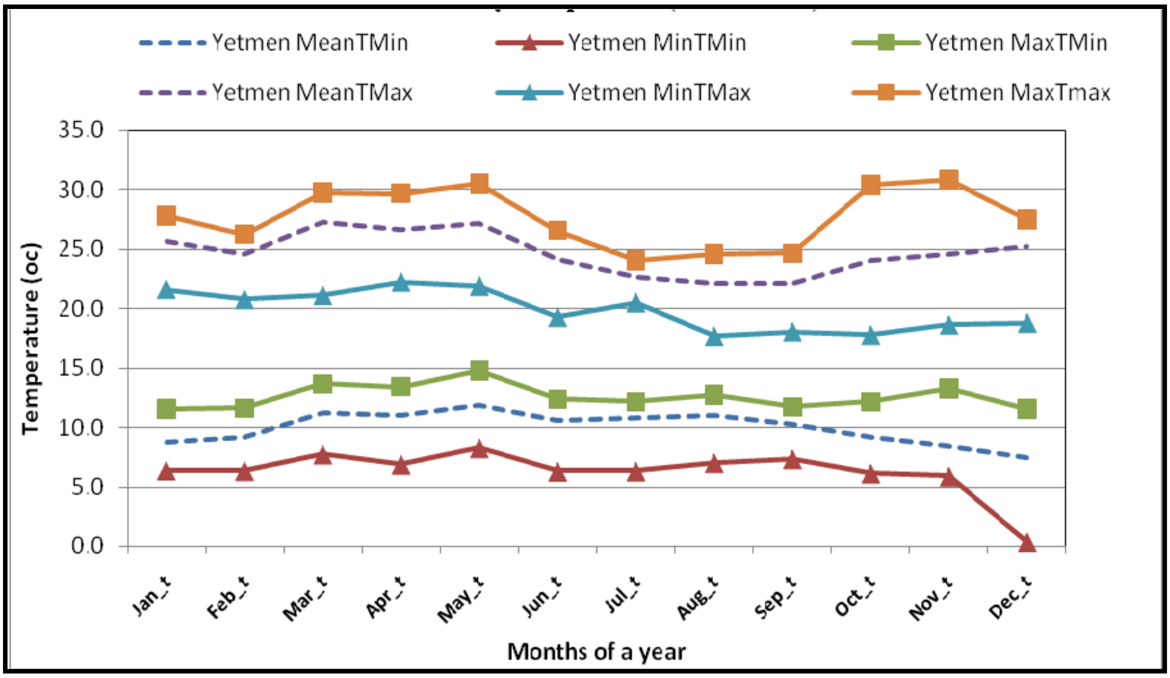


Figure 13. Average minimum and average maximum temperature pattern by month at Yetmen (1980-2008).

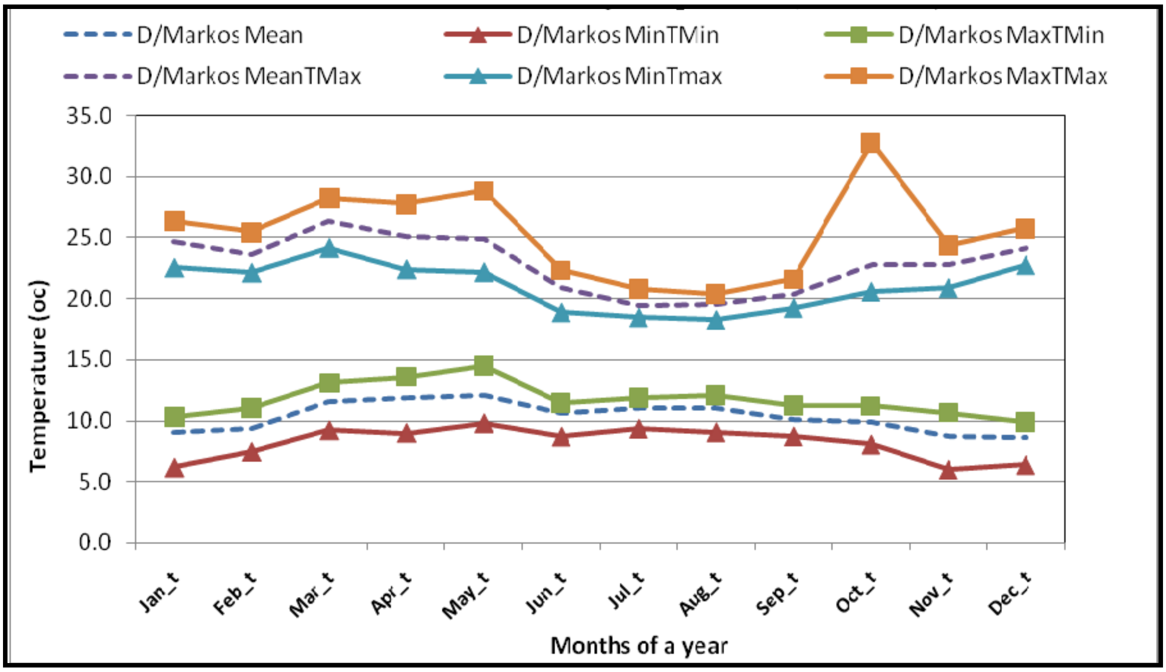


Figure 14. Average minimum and average maximum temperature pattern by month at Dangla (1979-2008).

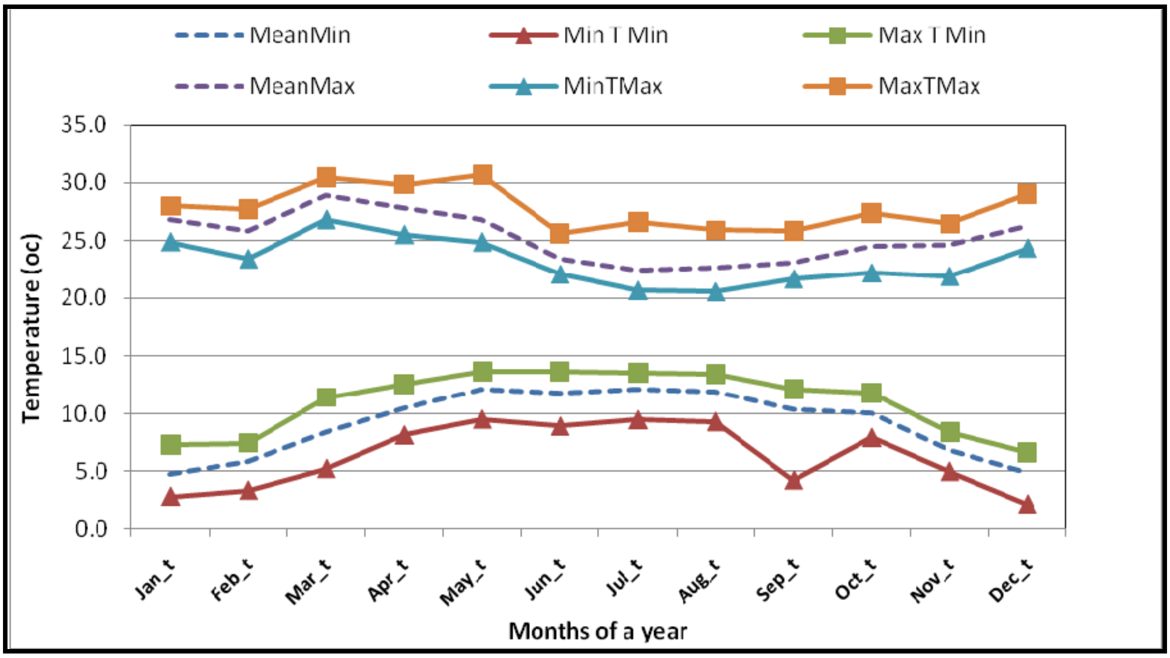


Figure 15. Average minimum and average maximum temperature pattern by month at Debre Markos (1979-2008).

The observed data reveals that extreme maximum and minimum temperature of Debre Markos recorded during October (32.8 ^{o}C) and November (6.0 ^{o}C), respectively. The lowest recorded of minimum temperature of Motta was 4.7 ^{o}C during January. Whereas the highest of maximum temperature of Yetmen was 30.8 ^{o}C recorded during November.

2.3. Minimum and Maximum Temperature Trends

In Bahir Dar minimum and maximum temperature has significant increasing trend. Plus Motta indicated that significantly increasing trend of minimum temperature, but no significant trend on maximum temperature. Both minimum and maximum temperatures were significantly increased at Debre Markos during the observation time (Table 7).

Table 7. Minimum temperature and maximum temperature (^{O}C) trends in Bahir Dar, Motta, Yetmen, Debre Markos and Dangla (1979-2008)

	Slope		Spearman`s rho		t_t (calculated value)	
Station	MinT^{o}	MaxT^{o}	MinT^{o}	MaxT^{o}	MinT^{o}	MaxT^{o}
Bahir Dar	0.08	0.02	0.71*	0.45*	6.29	4.00
Motta	-0.01	0.01	0.19*	0.09	2.15	1.30
Yetmen	0.06	0.07	0.40*	0.77*	3.63	7.17
Debre Markos	0.03	0.01	0.79*	0.31*	7.61	6.00
Dangla	0.02	0.03	0.40*	0.60*	3.63	3.10
Areal mean	0.19	0.05	0.71*	0.40*	6.34	3.66

*Significant at 0.05 levels, Critical value, 2.04

In general the characteristics of minimum and maximum temperatures in western Amhara reveal significant increasing trends, but the rate was slightly higher for a minimum than the maximum temperature in almost all study stations during the observation period.

The analysis of temperature data on the record showed that the areal mean of minimum and maximum temperatures has increased trend. Figure 16 depicts a very strong linear relationship, particularly minimum temperature (R^2=0.55), between time and temperature.

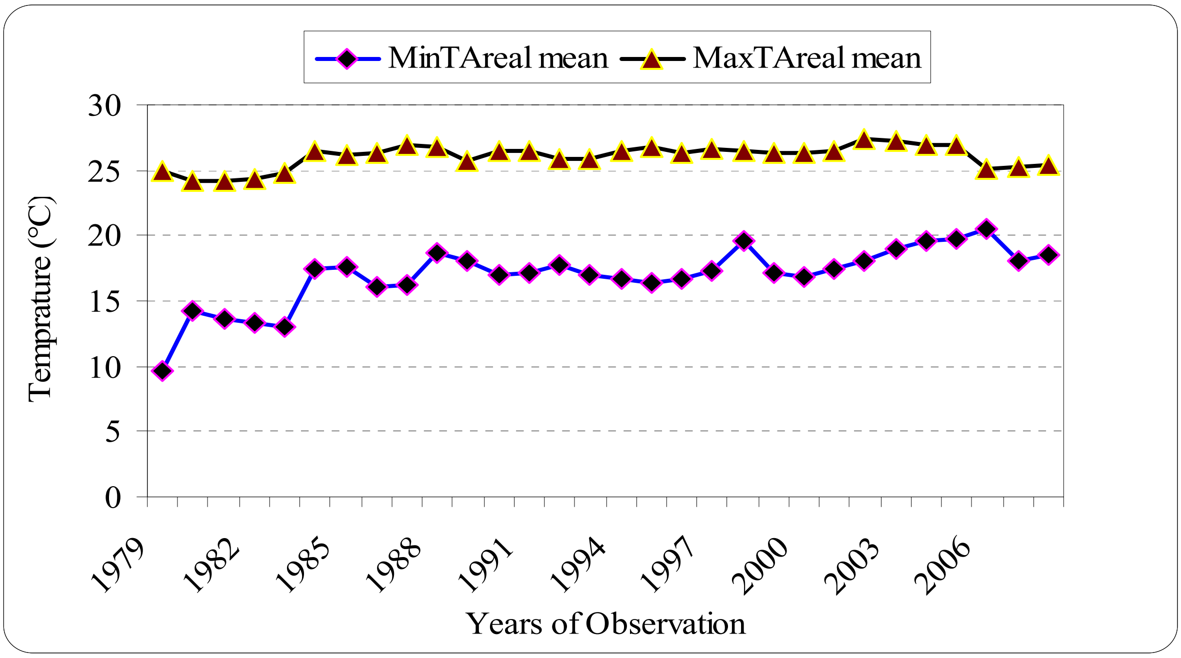


Figure 16. Areal average of minimum and areal average of maximum temperature of estern Amhara (1979-2008).

In general, from monthly average minimum and maximum temperature of the study area can be concluded that, western Amhara characterized by a significant increment of minimum and maximum temperature. In addition Annual average minimum and maximum temperature and trend of western Amhara show a significant increase during the observation period (Appendix G, H and I).

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusion

This study has presented an analysis of the spatial and temporal behavior of rainfall, maximum temperature and minimum temperature using data obtained from five meteorological stations of Western Amhara from the year 1979 to 2008. The main findings of the study are summarized below.

The result showed that, there was a considerable spatial variation of rainfall and temperature over western Amhara. Among the different rainfall features considered during the study period, onset dates of rainfall, end dates and duration are found the most variables once. The annual total rainfall of western amahara varies from 878mm to 2100mm. For the period (1979-2008) the annual and kiremt rainfall shows statistically significant increasing trends in all study stations. The period (1995-2008) showed significant positive increasing rainfall trends in Bahir Dar, Motta, Yetmen and Debre Markos.

Variance of maximum temperature existed every month in all stations. However, its intensity increased from the month of October to May but decline from June to September and reaches the extreme point during March, April and May. Similarly, monthly average minimum temperature showed variation in all stations; Such as, Bahir Dar, Debre Markos, Yetmen and Dangla minimum temperature intensity increased from February to September, whereas it showed a decreasing trend from October to January. On the other hand monthly average minimum temperature pattern showed a unique increasing and decreasing pattern at Motta relative to another station.

Generally, this study has shown that there are significant inter- annual variations of rainfall, plus differences in rainfall amount and trend has been observed between stations too. Further, variation in monthly and inter-annual minimum and maximum temperature patterns has noted in the study area. The spatio-temporal variability of rainfall, minimum temperature and maximum temperatures are alarming and will help practitioners, particularly water resource managers, agricultural development planners and ecosystem managers, program designer for their strategic planning and decision making processes.

2. Recommendations

- ♦ assessing the risk of temperature and rainfall variability is crucial for the purpose of planning calendars for cold sensitive crop, such as rice, to produce high value fruits and vegetables.
- ♦ providing accurate prediction and projection of climate variability is so important, such as; to help make decisions about how crop are grown and managed, to estimate yields to help government and incorporate decision about buying and selling products, to improve management method.
- ♦ further, assessment of climate variability is also crucial, not only to design adaptation strategies but also to setting an agenda for development policy and research.

However, for improving precision and reliability of the application of the findings for practical use, increasing numbers of the study stations and periods would be crucial.

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