Full Length Research Paper

Variability of rainfall and its current trend in Amhara region, Ethiopia

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In most of African countries whose economy is heavily depending on rainfed agriculture, accurate estimation of the spatial and temporal distribution of rainfall and observing its trends are crucial input parameters for securing sustainable agricultural production. This paper examines the spatial and temporal rainfall characteristics of Amhara Region, Ethiopia; using standard rainfall statistical descriptors. For this purpose, 10 meteorological stations with 30 years of daily rainfall data have been used. Variations of rainfall were found in every month in all stations. The spatial distribution of annual rainfall was varied from 850 to 1485 mm. Belg ("small rainfall" in March – May) rain makes a considerable contribution to the annual total in the central and eastern stations of the region. Annual rainfall has shown negative and positive anomalies for much of the 1980s and 1990s, respectively. Although the long term movements of rainfall in a time series did not show any increasing or decreasing trend, contraction of the length of growing period due to early cessation of rainfall had been observed in recent years. However, for improving precision and reliability of the application of the findings for practical use, increasing the number of study stations is found central.

Key words: Africa, Ethiopia, Amhara, belg, spatial and temporal variability, rainfall trend.

INTRODUCTION

Climate change is real and happening now. The average global surface temperature has warmed 0.8°C in the past century and 0.6°C in the past three decades (Hansen et al., 2006). The effects of climate change such as rising temperature and changes in precipitation are undeniably clear with impacts already affecting ecosystems, biodiversity and people (IPCC, 2001). Associated with global warming, there are strong indications that rainfall changes are already taking place on both the global and regional scales (Hulme et al., 1998). Changes in the patterns of rainfall and its impact on vegetation and animal life including humans, is an important climatic problem facing society today. It plays statistically significant roles in many physiological processes, from conception and growth to health and disease (Davidson et al., 2003). One region of the world where the effects of climate change are being felt particularly hard is Africa. Because of the lack of economic, development, and institutional capacity, African countries are likely among the most vulnerable to the impacts of climate change (IPCC, 2001). Climate change impacts have the potential to undermine and even, undo progress made in improving the socio-economic well-being of East Africans. Many studies indicated that one of the most widespread and potentially devastating impacts of climate change in East Africa will be changes in the frequency,

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intensity, and predictability of rainfall. Changes in regional rainfall will ultimately affect water availability and may lead to decreased agricultural production and potentially widespread food shortages (Hulme et al., 2001; IPCC, 2001).

In Ethiopia, agriculture remains the most important sector of the economy. The contribution agriculture to the national economies through food supply, employment creation, export earnings, etc. is enormous (CSA, 2005; FAO, 2006), but it is predominantly rainfed. Therefore, changes in rainfall conditions have a direct and immediate impact on the performance of agricultural sector as well as on the country's total GDP (Hassan, 2006; FAO, 2006).

Rainfall in much of the country is often erratic and unreliable; rainfall variability and associated droughts have historically been major causes of food shortages and famines (Wood, 1977; Pankhurst and Johnson, 1988). According to von Braun (1991), for instance, a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in the country's food production. It was further noted that in a study conducted in Oromiya region at Debre Zeit and Kulumsa areas (Ethiopia), using wheat as a model crop, a 24 to 33% crop yield reduction was observed due to rainfall and temperature variation (MoWR, 2001).

Different researches had been conducted to assess the spatial and temporal patterns of rainfall in different parts of the country. Wing et al. (2008) in studied the trends and spatial distribution of annual and seasonal rainfall in different parts of Ethiopia using data from 134 stations in 13 watersheds between 1960 and 2002, and showed no significant changes in annual watershed rainfall for any of the watersheds examined, rather a significant decline in June to September rainfall (that is, Kiremt) were recorded in watersheds located in the southwestern and central parts of Ethiopia. Similarly, Osman and Sauerborn (2002) noted that summer rainfall in the central highlands of Ethiopia declined in the second half of the 20th century. On the other hand Seleshi and Zanke (2004) failed to find such a trend over central, northern, and northwestern Ethiopia. Instead, similar to Verdin et al. (2005) they found a decline of annual and Kiremt rainfall in eastern, southern, and southwestern Ethiopia.

Woldeamlak and Conway (2007) argued declining of annual rainfall in the northwestern part rather there were no clear trend of annual rainfall during their observation time. Generally, Wing et al. (2008) in many parts of Ethiopia, Woldeamlak and Conway (2007) in drought prone areas of Amhara region (Northwestern Ethiopia), Seleshi and Zanke (2004) in central, northern, and north-western Ethiopia and Conway et al. (2004) in the central Ethiopian highlands and Conway (2000) in northeastern Ethiopian highlands agreed that there is no significant and clear trend in the annual rainfall pattern. Contrasting results of trend in annual and seasonal rainfall in some parts of the country as explained by Easterling et al. (2000); Seleshi and Zanke (2004) might have been steamed

from the use of different periods, some studies have been based on areal averages (Seleshi and Demaree, 1995; Osman and Sauerborn, 2002) while others have been based on too few stations to be fully representative of the spatial variability in the study regions (Meze-Hausken, 2004; Seleshi and Zanke, 2004).

Rainfall is not well approximated by normal distributions (IPCC, 2001). However, as it has been noted by IPCC (2001) and Moberg and Jones (2005), development and analyzes regional/local specific daily rainfall data is important for a number of indices. In this day and age, assessing changes in rainfall condition has got due attention because of its importance for economic activities such as agriculture, energy production and drinking water supply, management and utilization of resources and due to their role in natural hazards such as droughts, floods, landslides and severe erosion. Therefore, the main objectives of this paper are to: 1. explore the spatial and temporal characteristics of rainfall in Amhara region, 2. assess the trends of rainfall in Amhara region for the period 1979-2008.

MATERIALS AND METHODS

The study area

Amhara region is located between 8°45′N and 13°45′N latitude and 35°46′ and 40°25′E longitudes (Figure 1). The total area of the region is estimated at 156, 960 km^2, which is divided into 12 administrative zones, 106 rural woredas and 3231 kebeles (CSA, 2008). Rugged mountains, plateaus, valleys and gorges characterize its physical landscape. Elevations range from 700 m a.s.l in the eastern part to over 4600 m a.s.l in the northwest. Areas lying below 1500 m a.s.l which covers 31% of the region are commonly classified as lowlands, (hot zone), between 1500-2500 m a.s.l covering 44% are classified as Woyina Dega (warm zone), and between 2500-4620 m a.s.l covering 25% of the region are classified as Dega (cold zone). The annual mean temperature of the region is between 15 and 21°C, but in valleys and marginal areas the temperature exceeds 27°C (FDRE, 1997).

Around 50% of the total area of the ANRS is considered tobe arable land. 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 wasteland (Lakew et al., 2000). Agriculture is the main livelihood of the people in the Amhara Regional State. More than 89% of the population live in rural areas and engaged primarily in crop-livestock mixed farming system (BoARD, 2006). The Amhara Regional State has a share of 15% in area, nearly 20% of population and 30% of total crop production of the country (CSA, 2008).

The region is characterized by erratic rainfall, high land degradation, high population density, high rate of poverty and malnutrition. Irrigated agriculture is negligible in the ANRS, although 500 000 ha of land are considered to be suitable for irrigation agriculture (IWMI, 2004). According to IFPRI (2007), the region loses annually an estimated 119 million tones agriculturally productive soil due mainly to water erosion; this results in agricultural productivity reductions of 2-3% per annum as a direct effect of the decrease in arable farmland and increased pressure on the remaining land. Moreover, it has been reported that only nearly 20% of the households cover their food requirements from their own production for three months only in many areas of the
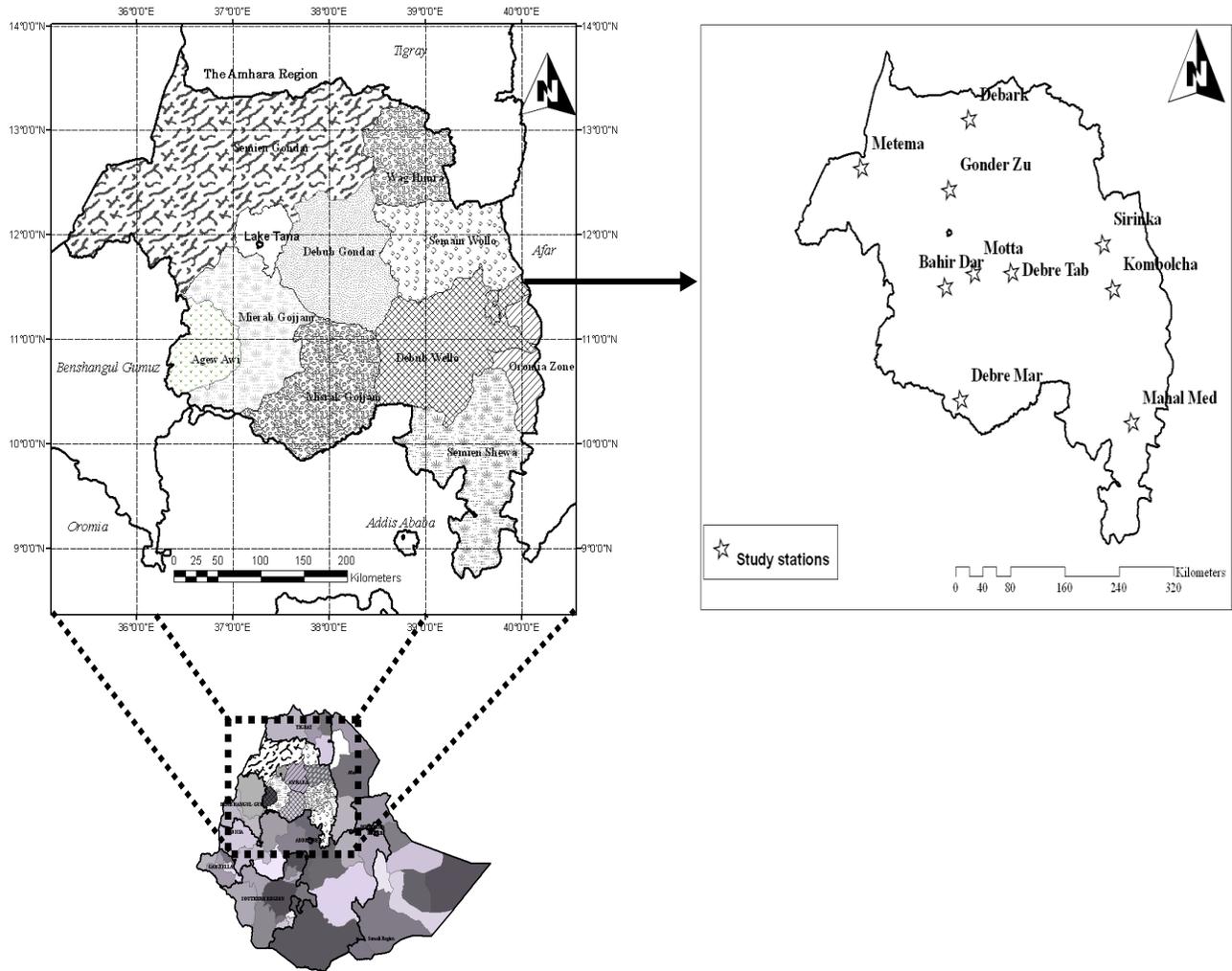
Figure 1. Geographical location of the ANRS and location of the 10 stations used in the study with reference to the whole country (Ethiopia).

Region, mainly due to natural hazards, uneven distribution of rainfall, land degradation and pest damage which all are related to climate variability. Overall, 2-3 million people are chronically food insecure in the region accounting for one third of the chronically food insecure and vulnerable people in the country (BoARD, 2006).

The data set and statistical analysis

Precipitation data of daily rainfall record for the selected stations (Table 1) from the period 1978-2008 were obtained from the National Meteorological Services Agency of Ethiopia (NMSA), and monthly, seasonal and annual rainfalls were derived from the daily data of those stations. To determine a common period to all the rainfall stations, some missing data were calculated using INSTAT+ v. 3.36 first or second order Markov-chain simulation models (Stern and Knock, 2002). Data were carefully inspected for its quality and completeness. Further, data homogeneity test was done by using double-mass curve; which refers to a graphical procedure where the rainfall values of the station are accumulated on the Y-axis and the cumulative total of other stations (assumed to be homogeneous)

on the X-axis. Falling of plotted points along a straight line indicates data homogeneity (Kefyalew, 1994). After quality checking, rainfall data were subjected to detail analyses using sequences of statistical packages. At the outset, the Box and Whiskers plotting technique was used to illustrate the inter-seasonal spread of the rainfall series with respect to onset date, end date, and duration of the June-July-August-September (JJAS) rainfall.

The annual and seasonal patterns of the rainfall are examined for all 10 stations based on inter-seasonal spread of the rainfall: March-April-May (Belg) and June-July-August-September (Kiremit or main) rainfall. Coefficient of variation (CV) was calculated as the ratio of standard deviation to the mean (NMSA, 1996) and in order to study monthly variability of rainfall in the study area, a modified version of Oliver's (1980) Precipitation Concentration Index (PCI) (De Luı´s et al., 1999) is used. This index, described as:

$$PCI = 100 \times [\textstyle\sum Pi^2 / (\sum Pi)^2]$$

Where: Pi = the rainfall amount of the ith month; and $\sum$ = 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

Table 1. Geographic information of the selected weather stations used for this study.

Weather station	Latitude (N)	Longitude (E)	Altitude (m)	Years of observation	No. of years with no data
Bahir Dar	11°36′	37°23′	1840.00	1979-2008	-
Debark	13°08′	37°54′	2850.00	1979-2008	-
Debre Markose	10°20′	37°43′	2446.00	1979-2008	-
Debre Tabore	11°51′	38°10′	2706.00	1979-2008	-
Gonder Zuria	12°36′	37°28′	2133.00	1979-2008	-
Kombolcha	11°34′	39°44′	1842.00	1979-2008	-
Mahal Meda	9°97′	39°69′	2400.00	1979-2008	-
Metema	12°58′	36°12′	685.00	1979-2008	-
Motta	11°50′	37°60′	2487.00	1979-2008	-
Sirinka	11°80′	39°31′	1850.00	1979-2008	4

values above 21 indicate very high concentration Oliver (1980). Further, as 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, which is described as:

$$SRA = (Pt - Pm)/ó$$

Where SRA = standardized rainfall anomaly, Pt = annual rainfall in year t, Pm = is long-term mean annual rainfall over a period of observation and ó = 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).

The least square regression and the Spearman's *rho* test were used to quantify trend and to test statistical significance of the trend respectively. Moreover, the monthly rainfall series of all the stations were used to calculate an areal average rainfall for the region as follows (Nicholson, 1985):

$$Rj = Ij -1Σ Xij$$

Where *Rj* is areally integrated rainfall for year *j*; *Xij* is rainfall at station *i* for year *j* and *Ij* is the number of stations available for year *j*. Variability and trend in the areal rainfall were also examined using the same methods.

The spatial variability of rainfall for seasonal and annual totals across stations has been analyzed and mapped using Inverse Distance Weighting (IDW) technique used for interpolation in ArcGIS 9.2 software Tung (1983) and Watson and Philip (1985).

To get a greater insight into the trends of rainfall in Amhara region and as a support for the least square regression and the Spearman's *rho* test, the areal rainfall trends obtained using Nicholson (1985), were analyzed using the software INSTAT+v3.36. This was done following a time series analysis in instat climatic guide as settled by Stern et al. (2006). (Note: INSTATT + v3.36 is a statistical package Produced by the Statistical Services Centre at the University of Reading, UK).

RESULTS AND DISCUSSION

Spatial variability of seasonal rainfall in Amhara region

Characteristics of rainfall features

The start and end of the rainy seasons were plotted using the box and whiskers techniques to examine whether there has been any shift in either direction for the data on record or not (Figure 2). The plot showed that, the onset of rainfall data were not symmetrical about the median, it means the start of the rainy season has been undergoing with little shift for most of the study stations. Relative to day of the year (DOY) 167 (June 15), which was the date when long rains used to start in the region, the mean onset date in day of year in the study area ranged from DOY 145 (Debre Tabore) to 186 (Sirinka). Moreover, onset date shows variability at Debre Tabore with CV of 15% and SD of 21.4 day of year. On the other hand, the smaller inter-quartile range noted in Debark and Debre Markose stations suggests a middle clustering of data about the median, it means the start of rainy seasons have been undergoing without delay and shift. Further, it could be noted from Figure 2 that, end date of rains was noted shorten in most of the study stations relative to DOY 308 (third of November) the date when rain normally used to cease in most parts of the region. Indeed, this results in contraction of the length of growing period (rainy days) in the region (Figure 2). The average date of end of rainfall ranged from DOY 266 (September 22) at Mahil Meda to DOY 304 (October 30) at Debark. Sirinka, Mahil Meda and Kombolcha have noted the least duration (<100 days) of JJAS rainfall in the region, Where as, Motta, Bahir Dar, Debark and Debre Markos noted long duration (>140 days) of JJAS rainfall.

Mean annual rainfall

The long term mean annual rainfall of the Region is 1165.2 mm. However, the spatial distribution of the long term mean annual rainfall varies from slightly over 850 mm in Mahil Meda to >1485 mm in Debre Tabore in the period of observation, with a standard deviation of 238.9 and 210.2 mm and a variability coefficient of 27.5 and 14.2%, respectively (Figure 3). Five stations (Gondar, Motta, Debark, Debre Markose and Bahir Dar) received 1100 to 1360 mm of mean annual rainfall per year. while, two stations (Mahil Meda and Metema) experienced
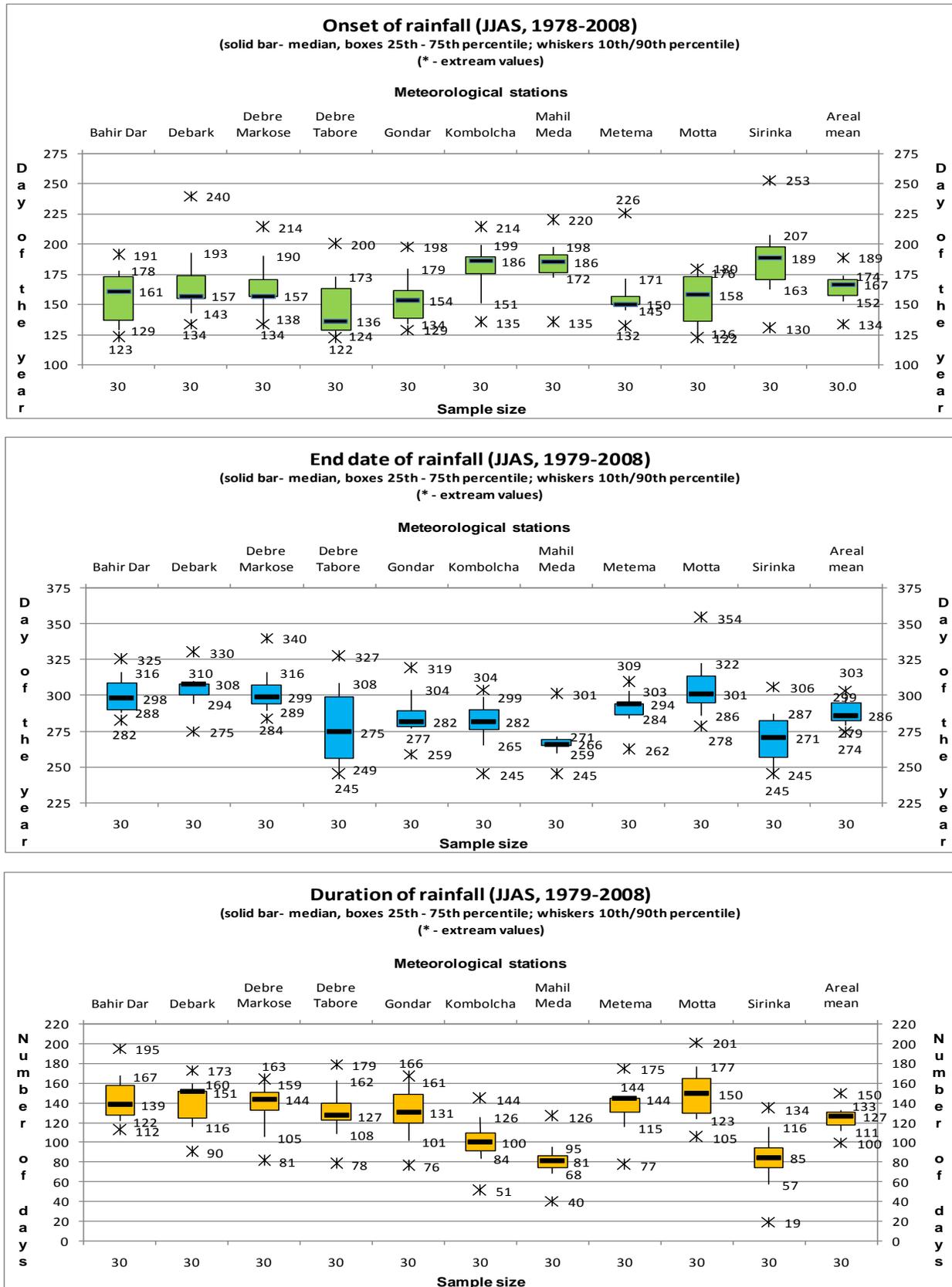
Figure 2. Box and whisker plots for start date, end date and duration of the rainfall for Kiremt (June – July – August – September) rainy seasons in Amhara region (dBase: 1979-2008).
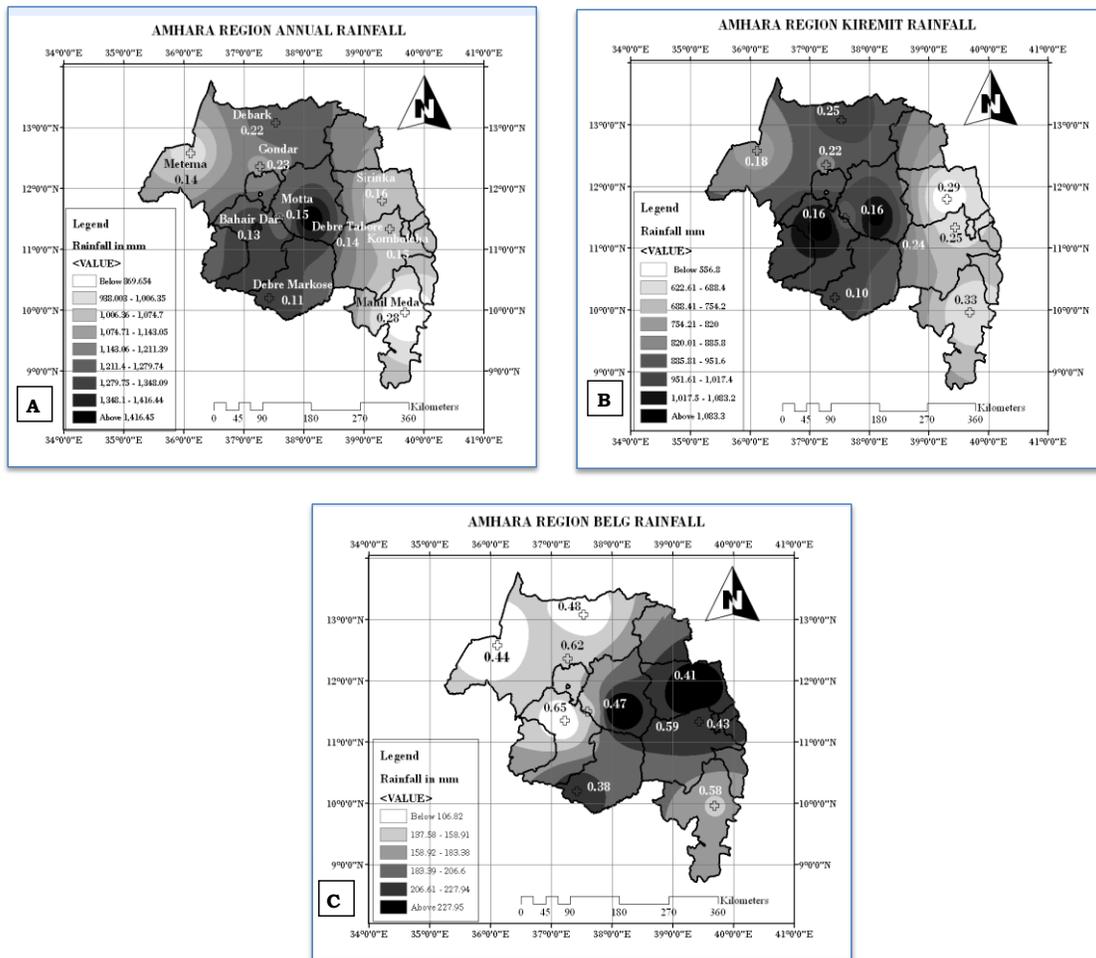
Figure 3. Images showing the spatial distribution of mean annual rainfall, (A) mean Kiremit rainfall, (B) and mean Belg rainfall, (C) with their coefficient of variations over 30 years average (1979-2008) mapped using ArcGIS 9.2 software.

mean annual rainfall amounts of <1000 mm. The other Stations (Kombolcha and Sirinka) received mean annual rainfall amount of nearly 1000 mm per year.

Kiremt season rainfall (Main rainfall from June to September)

The region heavily experiences high rainfall during kiremit (main rainy) season. 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 ITCZ. This season contributes more than 74.3% for the mean annual rainfall of the region (Table 2). The mean annual rainfall of kiremt season in the region is 866.27 mm and all the stations receive more than 866.7 mm rainfall per year (Figure 3). Bahir Dar received the maximum mean annual kiremt rainfall followed by Debre Tabore (Table 2 and Figure 3). The contribution of *kiremt* rainfall to the average annual

rainfall across station is also very high, it ranges from 55.02% at Sirinka to 84.42% at Bahir Dar and followed by Metema which is 81.92% (Table 2).

Belg season rainfall (small rainfall in March to May)

From the present study it was possible to note that, Belg (short rain from Match – April – May) rainfall makes a considerable contribution to the annual total in the more easterly stations of Sirinka and Kombolcha 24.84 and 21.50%, respectively (Table 2). Similarly, the NMSA (2005) set that, central parts of northern high lands, eastern highlands, parts of central, southwestern and southern Ethiopia are known as Belg growing areas. Further, in better agreement with the present study, the NSMA (2005) noted that, the contribution of Belg rainfall over the north, northeastern and eastern highlands is ranging from 5 to 30%. According to Seleshi and Zanke (2004), the rainfall during Belg over parts of central Ethiopia where Sirinka

Table 2. Average contribution of the three seasons and the highest monthly rainfall contribution to the annual average (in percent) and the Precipitation Concentration Index (PCI), 1979–2008.

Station	Kiremt rainfall	Belg rainfall	Bega rainfall	Highest mean monthly rainfall	PCI
Bahir Dar	84.42	7.85	7.73	33.38	20.6
Debark	78.95	9.07	11.98	31.98	18.0
Debre Markose	72.60	16.60	10.79	24.79	15.3
Debre Tabore	75.11	17.98	6.91	29.72	17.2
Gondar	77.89	13.50	8.60	29.02	18.2
Kombolcha	64.87	21.50	13.64	28.76	15.3
Mahil Meda	72.90	18.01	9.12	36.43	20.7
Metema	81.92	12.09	6.05	27.19	19.1
Motta	75.05	12.55	12.40	27.77	17.0
Sirinka	55.02	24.84	20.12	23.79	12.3

and Kombolcha located was due to migratory low-pressure systems originating in the Mediterranean area and move eastward and interact with the equatorial/tropical systems which causes the south-easterly winds from the Indian Ocean blowing towards a thermal low (cyclone) which develops over the south of Sudan during this season and produces rains in March, April and May.

Generally, rainfall in Amhara region show moderate inter-annual variability as shown by the coefficients of variations (Figure 3). The Belg and the Bega rainfalls are found much more variable (>30%) than the Kiremt rainfall in which the coefficient of variation is lower than 30%. A similar conclusion that Belg and Bega rainfalls are more variable than Kiremt rainfall was arrived at by Woldeamlak and Conway (2007) in their study that analyzed rainfall data from 12 stations in drought-prone areas of Amhara Region, Ethiopia.

From the present study, it was possible to note that, the highest monthly totals of about 23.79 to 36.43% contributed to the annual total rainfall from Sirinka and Mahil Medda, respectively. Further, A PCI values noted between 12 and 20 indicate that, rainfall in Amhara region was characterized by high to very high monthly rainfall concentration (Table 2).

Inter annual fluctuations of rainfall

The standardized anomalies of annual rainfall at the 10 stations, during the periods between 1979 and 2008 noticed the proportion of negative anomalies ranged from 46.66% (in Debark) and 63.33% (in Gondar and Metema) of total number of observations (Figure 4).

All most in all stations annual rainfall has shown negative anomalies for much of the1980s. At Bahir Dar, annual rainfall showed positive anomaly for the 1998–2008 decade except 2007 when a slight negative anomaly has been occurred. During the wettest year's annual rainfall have been 1.857 times the standard deviations above the long term (1978 – 2008) average. However, annual rainfall was found 2.57 times the

standard deviation below the long-term (1978–2008) average during the drier years.

Significant positive anomalies in Gondar and Mahil Meda occurred during 1999–2001 and in 1980 and 1981, respectively. During the driest year, 1984, annual rainfall was 2.97, 2.16 and 2.85 times the standard deviation below the 1978–2008 mean rainfall at Sirinka, Mahil Meda and Kombolcha, respectively. Debark, Debre Markose and Debre Tabore stations noted annual rainfall of 2.78, 2.68 and 2.32 times the standard deviation above the 1978-2008 mean rainfall during 1988, 1993 and 1997, respectively (Figure 4).

Similar to most of the study meteorological stations, it is apparent that deviations of long-term areal annual rainfall from its long-term average were negative during 1980s, while deviations in the period 1995-2002 were dominantly positive in the series record (Figure 4). During the driest year, 1984, annual rainfall was 2.93 times the standard deviation below the 1978-2008 mean rainfall of the region. In better agreement with the result of Woldeamlak (2009), in this study, the year 1984 was come up with the lowest rainfall record in the region and showed the worst drought year.

Generally, the rainfall in the Amhara region was characterized by sporadic fluctuation of wet and dry years. The present study showed fifteen years negative deviations of areal annual rainfall from its long-term average, most of which was occurred during the 1980s. This statement agrees with the result found by Woldeamlak (2009). However, the rainfall showed some recovery and faintly progressed above the mean between the years 1995 – 2002. These years were the wettest years in the region during the period of observations (1979-2008).

Trends of rainfall in Amhara region

Autocorrelation and persistence analysis

The autocorrelation coefficient provides a measure of temporal correlation between rainfall data points with
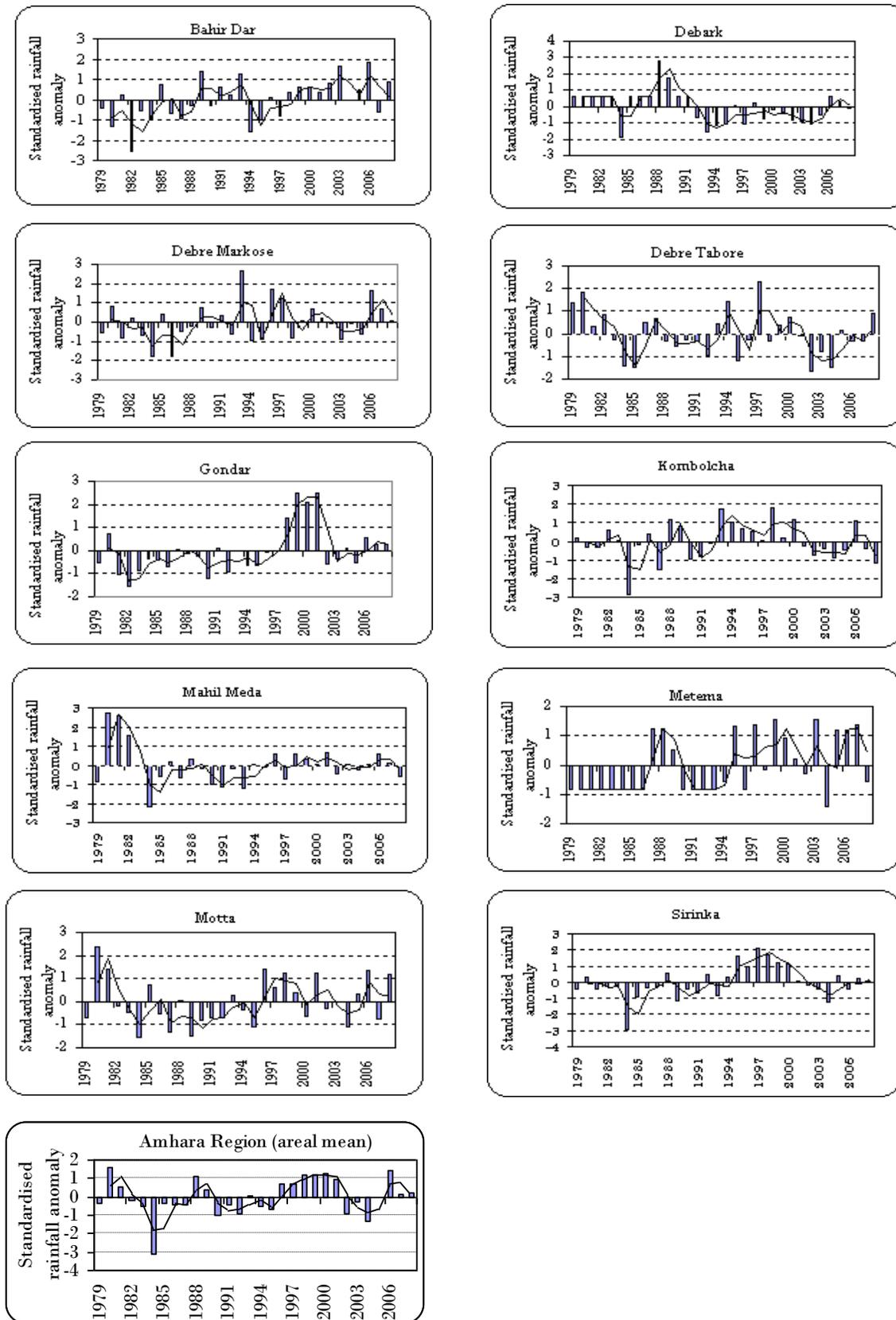
Figure 4. Standardized anomalies of annual rainfall in each station and over Amhara region (areal mean) for the period 1979 – 2008.
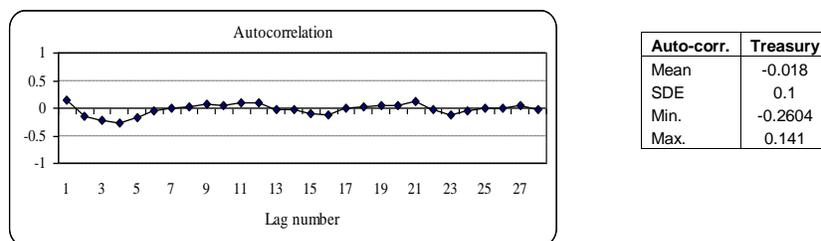
Auto-corr.	Treasury
Mean	-0.018
SDE	0.1
Min.	-0.2604
Max.	0.141

Figure 5. Autocorrelation of long-term areal annual rainfall in Amhara region (dBase: 1979-2008).

Table 3. Annual and seasonal rainfall trends in study meteorological stations for the period 1979-2008.

Station	Annual		Kiremt		Belg	
	Trend (mm/30years)	Spearman's rho	Trend (mm/30years)	Spearman's rho	Trend (mm/30years)	Spearman's rho
Bahir Dar	10.11	0.47 [b]	8.74	0.42[b]	1.04	0.09
Debark	11.87	-0.40 [b]	-11.01	-0.31	-1.07	-0.25
D/Markose	4.10	0.17	2.09	0.16	1.02	0.09
D/Tabore	-4.74	-0.23	-10.99	-0.34[a]	10.61	0.07[c]
Gondar	12.65	0.47[b]	11.16	0.54[c]	1.46	0.04
Kombolcha	0.83	-0.09	5.15	0.17	-4.79	-0.57[c]
M/Meda	-3.62	0.02	0.10	0.17	-2.21	-0.11
Mettema	7.18	0.59[c]	9.79	0.65[c]	-2.38	-0.21
Motta	2.53	0.11	3.69	0.18	-0.65	-0.10
Sirinka	5.50	0.24	11.28	0.45[b]	-3.35	-0.34[a]
Areal mean	2.25	0.15	2.75	0.21	-0.03	-0.09

[a] Significant at 0.1 level, [b] Significant at 0.05 level, [c] Significant at 0.01 level.

different time lags; namely 1, 2, 3... n years (Essenwanger, 1986; Brockwell and Davis, 1996). Likewise, autocorrelation of the areal annual average rainfall with a time series was made to see a tendency for a system to remain in the same state from one observation to the next or not.

Figure 5 shows that, all the autocorrelations fallen within 95% confidence limits and standard errors of 0.1; there was no apparent pattern (such as a sequence of positive autocorrelations followed by a sequence of negative autocorrelations). This means that there was no associative ability to infer from a current value of the time series to the next value. Similarly, Osman and Sauerborn (2002), in their study on preliminary assessment of characteristics and long-term variability of rainfall in Ethiopia using 1898 – 1997 data, noted that, there were no constant persistence in the observed precipitation series data for the central highlands of Ethiopia.

However, such non-association was the essence of randomness. In short, adjacent observations did not "correlate" (the areal average annual rainfall data indicated that no dependency and periodicity apparently existed in this time series and suggested areal average annual rainfall amounts are entirely independent from one year to the next).

Annual and seasonal rainfall trends in the study meteorological station

In this study, statistically significant increasing trends of annual and Kiremt rainfall were noted in Bahir Dar, Gondar and Metema, while, Sirinka and Debre Tabor show significant increasing trend during Kiremit and Belg rainfalls, respectively (Table 3). Other significant trends are decreasing annual rainfall in Debark, decreasing kiremt rainfall in Debre Tabore and decreasing belg rainfall in Sirinka and Kombolcha were noted (Table 3). However, no significant trend was recorded as far as the areal mean seasonal and annual rainfalls were concerned. Different research results had been noted as long as the annual and Kiremt rainfall trends in different parts Ethiopia are concerned and most of which are in conflict with one another. Similar with the present study, Woldeamlak and Conway (2007) in drought prone areas of Amhara region (Northwestern Ethiopia), Seleshi and
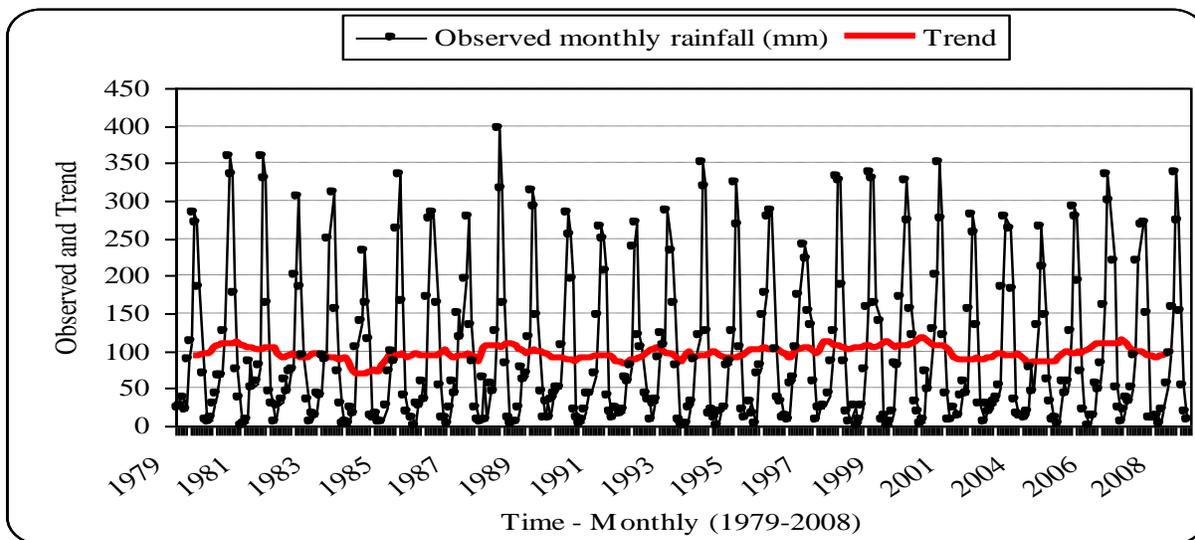
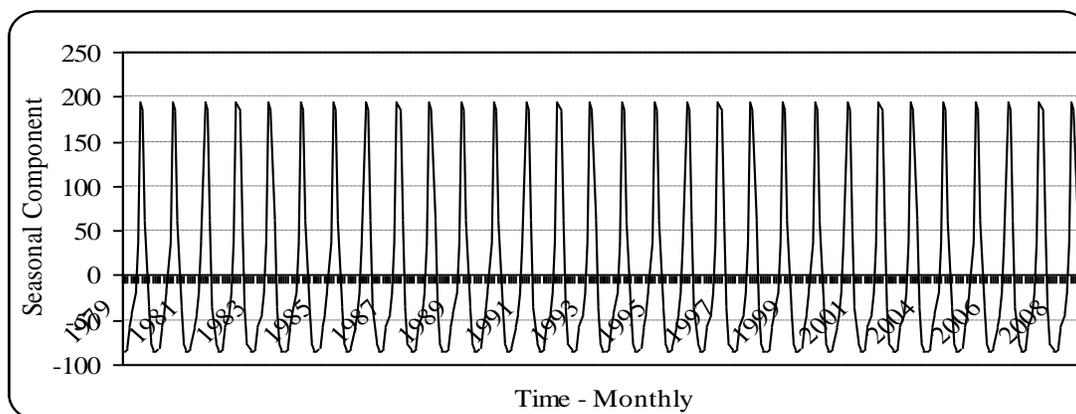**Figure 6.** Rainfall trend (dBase: 1979-2008).

Figure 7. Seasonal component of rainfall at Amhara region (dBase: 1979-2008).

Zanke (2004) in central, northern, and northwestern Ethiopia and Conway et al. (2004) in the central Ethiopian highlands and Conway (2000) in northeastern Ethiopian highlands agreed that there is no significant and clear trend in the annual rainfall pattern.

However, a significant decline in June to September rainfall (that is, Kiremt) was noted by Wing et al. (2008) in their study on trends and spatial distribution of annual and seasonal rainfall in different parts of Ethiopia using data from 134 stations in 13 watersheds between 1960 and 2002.

Trend of areal annual rainfall in Amhara region (1979 – 2008)

The long term movements of rainfall in a time series

(Figure 6) do not have underlying direction; means there was no any increasing or decreasing trend rather it fluctuates around the mean. However, It confirms that the amount of rainfall tend to peak in certain months in each year; showed seasonal fluctuation with in the year. This will help practitioners, particularly water resource managers, agricultural development planners and ecosystems managers, with their strategic planning and decision making processes (Mikelsen et al., 1998).

Comparatively following the trend line and observing the subsequent conditions for particular period of time, it can be easily noted that the area has been received low rainfall during 1984/85. More over a slight pattern of decreasing trend of rainfall was noted in recent years (2000 - 2007), indicates that the amount of rainfall tend to decrease (Figure 6).

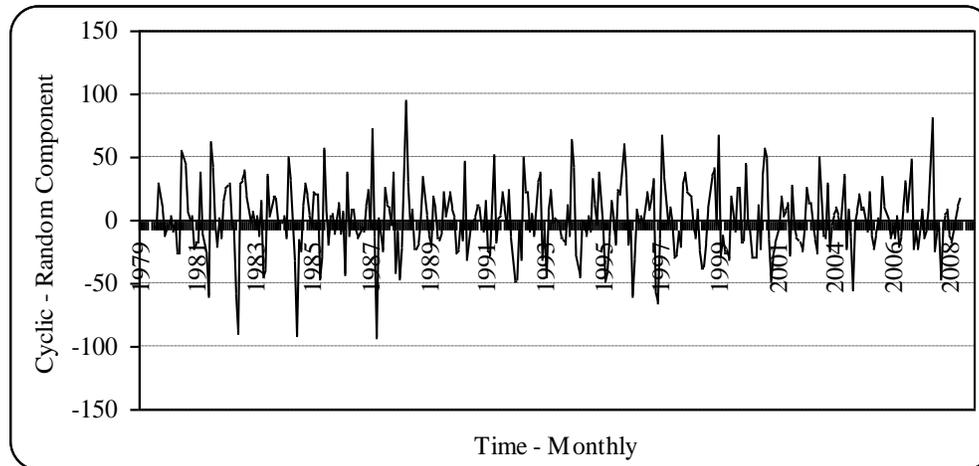The seasonal component of the rainfall in a time series

Figure 8. Cyclical-random component of rainfall at Amhara region (dBase: 1979-2008).

(Figure 7) was characterized by exhibiting oscillations at the same frequency in the correlogram. This means there existed a regular fluctuations with in a year (periodicity) indicating that Kiremt (rain from June – July – August – September) season still continued to contribute to the rainfall and rains are suppressed during dry season; otherwise it's not clear whether the amplitude of variability has been changed or not.

Figure 8 below shows the cyclical-random component of rainfall which denotes a kind of peak rainfall values some times. However, it's difficult to draw a clear picture whether the cyclic-random component of the rainfall follows a defined pattern or not, that means its periodicity is un-known. This finding contradict with the result by Woldeamlake and Conway (2007) in their note on the temporal and spatial variability of rainfall in the drought-prone areas of Amhara region of Ethiopia indicated that rainfall in the region showed substantial decadal variability; that is, persistence, a year with a positive anomaly tends to be followed by another year with a positive anomaly as do years with negative anomalies.

The cyclical-random component of rainfall indicated as drier conditions have been experienced in 1982, 1984, 1987, 1997, 2002 and 2004. Similarly, Agnew and Chappel (1999) in their study on drought assessment methods and Woldeamlak (2009), in his study on rainfall variability and crop production in Ethiopia; Case study in the Amhara region; noted that, there have been drought years in the Amhara region and the year 1984 was noted as extreme drought year. Once again, the year 1984 stands out the worst year, and the standardized rainfall anomaly reached nearly 3 in this study (Figures 4 and 8).

CONCLUSIONS AND RECOMMENDATIONS

This study has presented a detailed analysis of variability of rainfall and its current trend in Amhara region, using 10 station records between 1979 and 2008. The followings are the conclusions resulted from this study:

1. Variations of rainfall existed in every month in all stations. However, its intensity increased from the month of January to July but sharply decline from September to December.
2. Kiremt rainfall contributed the highest percentage of rainfall at the region.
3. The mean annual rainfall of the region was 1165.2 mm; the maximum rainfall (>1485 mm) was recorded at Debre Tabore (Central part), and the lowest of region (850 mm) was recorded at Mahil Meda (South eastern part).
4. Rains in recent years tend to end early; this resulted in contraction of the duration of rainy days in the region.
5. There are no dependencies and periodicities apparently exist in this time series (1979–2008), this suggests that annual precipitation amounts are entirely independent from one year to the next.

Generally, for improving precision and reliability of the application of the findings for practical use, increasing number of study stations would be crucial. However, this finding will help practitioners, particularly water resource managers, agricultural development planners and ecosystems managers, with their strategic planning and decision making processes.

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