Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers’ perception

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ABSTRACT

Rainfall is the most important but variable climatic parameter in the semiarid tropics. In this study, the trend and variability of rainfall were compared with the perception of farmers in northern Ethiopia. Daily rainfall data obtained from five meteorological stations located in different agroecological zones were used to determine trends in annual and seasonal totals, onset and cessation dates, length of growing period (LGP) and dry spell length. Sen’s estimator and Mann-Kendall’s statistical tests were used for trend detection. Two hundred fifty three farmers from three administrative areas (districts) that are close to the meteorological stations were interviewed in order to investigate farmers’ perception on rainfall trend and variability in the study area. The results indicate that rainfall in the region is highly variable with a non-significant trend in both annual and seasonal totals for all stations. However, trends of rainfall events such as onset date, cessation date, LGP, and dry spell length were changed significantly in most stations, which agreed with the farmers’ perception. Moreover, most stations experienced drought conditions in the last decade. The results suggest the need for designing appropriate agronomic and water management strategies to offset the negative impacts of rainfall variability in the study area.

Key words: Rainfall, rainfall trend, rainfall variability, onset, length of growing period.

INTRODUCTION

Agriculture plays a dominant role in the economy of Ethiopia, contributing 41% GDP, 80% of the employment and the majority of foreign exchange earnings (Gebreegziabher et al., 2011). The success of agricultural production has, therefore, large implications, ranging from the state of the countrywide economy to the survival of the subsistence farmers (Block and Rajagopalan, 2007). Natural rainfall is the main source of water for crop production as irrigation covers only 5% of the cultivated land in the country (Awulachew et al., 2010). Several studies (Hagos et al., 2009; Osman and Sauerborn, 2002) examined the impact of rainfall variability on the Ethiopian economy, and found that rainfall variability in the country led to a production deficit (20%) and increase in poverty rates (25%) which costed the economy over one-third of its growth potential.

Assessing trends in rainfall characteristics based on past records together with the perception of the local community is essential to develop adaptation strategies. Previous studies dealing with annual and seasonal rainfall trends in Ethiopia revealed controversial results. Seleshi and Demaree (1995); Osman and Sauerborn (2002) indicated high rainfall variability and its negative trend during the main rainy season (June-September). Using data in the last half a century, NMSA (2001) reported a significant reduction in annual rainfall in the north, southwest part of the country while there was an increasing trend of annual rainfall in the central part of Ethiopia. Considering rainfall data of the Amhara Region (North West Ethiopia), Bewket and Conway (2007) reported inconsistent results in the annual, kiremt and Belg rainfall trends within the stations of the region. The authors
noted that for the period 1975-2003, kiremt and annual rainfall shows significantly increasing trend at Dessie and Lalibela while Debre Tabor revealed significantly decreasing rainfall trend during both seasons. On the other hand, Meze-Hausken (2004); Seleshi and Camberlin (2006); Cheung et al. (2008) did not find any significant trend over the northern and northeastern part of the country.

Previous studies on rainfall analysis concentrated on the central highlands of the country (Seleshi and Demar’ee, 1995; Osman and Sauerborn, 2002; Cheung et al., 2008). Moreover, data obtained from a single observatory station have been used to study the spatial and temporal variability of rainfall in the study region (Meze-Hausken, 2004; Seleshi and Zanke, 2004). However, as topography and elevation of the region is highly variable, this could easily miss localized trends and variability. Studies of rainfall variation generally focusing on large areas would be of no use for local agriculture, particularly in places where rainfall is highly variable (Murugan et al., 2008).

Although information on rainfall characteristics in dry land areas is critical for agricultural planning, many studies (e.g., Meze-Hausken, 2004; Seleshi and Zanke, 2004) used seasonal or annual totals for trend analysis. Nevertheless, farmers evaluate rainfall variability in relation to their agricultural practices based on its amount, onset and cessation at intervals of days or even hours which do not match with results rainfall analysis based on annual or monthly totals. Therefore, there is a gap in relating rainfall analysis with the local farmers’ observation who is the ultimate user of the finding. Understanding farmers’ views could offer important insights on the nature of environmental processes that the analysis of scientific data alone cannot capture (West et al., 2008). However, studies that involve both the analysis of historical records and the perception of the local farmers’ are not available in Ethiopia. Therefore, the objectives of this study were to analyze trends and variability of rainfall parameters and to explore the relation between the results of the historical rainfall analyses and the perception of farmers’ in northern Ethiopia.

**METHODOLOGY**

**Background of the study area**

The study was conducted in the Tigray Regional State which is located in the northern escarpment of Ethiopia between 36°-40°E longitude and 12.5°-15°N latitude. It borders with Eritrea in the north, Sudan in the west, Amhara Regional State in the southwest and Afar Regional State in the east. The landform is complex composed of highlands (in the range of 2300-3200 m.a.s.l) and lowland plains (with an altitude range of 500-1500 m.a.s.l). It has diversified agro-ecological zones and niches each with distinct soil, geology, vegetation cover and other natural resources. The climate is mainly semi-arid and, for most of the region, the main rainy season (locally called kiremt) lasts for 3 to 4 months, between June and mid-September (Araya et al., 2010; Gebrehiwot and van der Veen, 2013). Moreover, some part of the region also gets a small rain shower (locally known as Belg) from February to May. There is great inter-annual spatial and temporal rainfall variation. In all months except the month of August, the decadal reference evapotranspiration (ET₀) exceeds the mean decadal rainfall (Araya et al., 2010).

The area was chosen for the study because of recurrent drought and crop failures that are common in this part of Ethiopia (Gebrehiwot and van der Veen, 2013). As the farmers in this area have been experiencing drought frequently, their perceptions on drought are valuable. Daily rainfall data of five stations, which lie within the different agroecological zones of the region, were used for this study. The stations together with their geographical descriptions and length of database considered are shown in Table 1 and Figure 1.

**Data source**

Daily rainfall data of different stations with various duration were obtained from the National Meteorological Service Agency (NMSA) of Ethiopia, Mekelle University, Tigray agricultural research institute (TARI) and Bureau of Agriculture and Natural Resource in the respective districts. The stations were selected based on the length of a record period and the relative completeness of the data. The world meteorological organization has recommended 30 years as a minimum data required for searching evidence of climatic change in hydroclimatic time series (IPCC-TGIA, 1999). Based on this criterion, eight stations were identified. However, continuous and long term database is hardly found in the study region as it was a site of conflict during the past regime. Thus, considering the maximum flexible thresholds of 10% missing values adopted by Ngongondo et al. (2011), only five observatory stations were remained. On the other hand, 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 (Stern et al., 2006). Then, the generated data were checked for their physical representative of the respective site. INSTAT plus was also used to summarize the daily data into annual, monthly and seasonal totals and to analyze the onset and cessation of the rainy season and length of growing period (LGP).

**Data quality control**

**Outlier detection:** Identification of outliers (suspicious data) has been the primary emphasis to the climate database development (Gonzalez-Rouco et al., 2001). Outliers are values greater than a threshold value of a
specific time series data that can affect the detection of inhomogeneity (Gonzalez-Hidalgo et al., 2009). For non-normally distributed data like rainfall, the Tukey fence is recommended for trimming the outlier (Ngongondo et al., 2011). The primary objective of outliers trimming is to reduce the size of the distribution tails in order to make a safer use of the nonresistant homogenization techniques used later (Gonzalez-Rouco et al., 2001).

In this particular study, the Tukey fence outlined in Ngongondo et al. (2011) were used to screen the outliers. It is the data ranges:

$$[Q_1 - 1.5 \times IQR, Q_3 + 1.5 \times IQR]$$.

Where $Q_1$ and $Q_3$ are respectively the lower and upper quartile points, 1.5 are standard deviations from the mean, and $IQR$ is the interquartile range. Values outside the Tukey fence are considered as outliers. In this study, such outliers
were set to a limit value corresponding to ±1.5×IQR.

**Homogeneity test:** The second step of the quality control process involved a homogeneity analysis. There are different methodologies that used to analyze homogeneity. In this particular study, due to its lower demands in application and interpretation as well as the poor correlation between stations, cumulative deviation test was used for absolute testing (using stations own data). This method was commonly used in the climatology to detect inhomogeneities in the meteorological time series (Sahin and Kerem, 2010; Ngongondo et al., 2011; Kang and Yusof, 2012). Buishand (1982) noted that tests for homogeneity can be based on the adjusted partial sums or cumulative deviations from the mean and it is given as follows:

\[
S_0^* = 0 \text{ and } S_k^* = \sum_{i=1}^{k} (y_i - \bar{y}), \quad k = 1, \ldots, n
\]

The term \( S_k^* \) is the partial sum of the given series. If there is no significant change in the mean, the difference between \( Y_i \) and \( \bar{Y} \) will fluctuate around zero. The significance of the change in the mean is calculated with 'rescaled adjusted range' \( R \), which is the difference between the maximum and the minimum of the \( S_k^* \) values scaled by the sample standard deviation as:

\[
R = (\max_{0 \leq k \leq n} S_k^* - \min_{0 \leq k \leq n} S_k^*) / SD
\]

Then the critical value for \( R / \sqrt{n} \) is calculated by Buishand (1982) and for n=30 its value is 1.5 and 1.4, respectively for 5 and 10% probability levels.

**Test of randomness and persistence:** It is well known that the time series data required for trend analysis should be random and/or non-persistent (Ngongondo et al., 2011). Portal and Kahya (2006) noted that one of the problems in the analysis and interpretation of trends in hydrological data is the confounding effect of serial dependence. Furthermore, in the presence of positive serial correlation, the non-parametric test could signify a significant trend, while in fact, due to random effects of the data series (Kulkarni and Van Storch, 1995). In this study, before proceeding to trend analysis, the time series data was tested for randomness and independence using the autocorrelation function \( (r_1) \) as described in Box and Jenkins (1976) in the following manner:

\[
r_i = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(x_{i+1} - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}
\]

Where \( x_i \) is an observation, \( x_{i+1} \) is the following observation, \( \bar{x} \) is the mean of the time series, and \( n \) is the number of data. In addition, Dahmen and Hall (1989) defined the critical region at 5% probability as follows:

\[
\left[ (-1 - 1.96\sqrt{(n - 2)})/(n - 1), (-1 + 1.96\sqrt{(n - 2)})/(n - 1) \right]
\]

Serial correlation of lag-1 (the correlation of two consecutive observations in the time series data) was employed in this study. Whenever significant correlation appeared in the data series, the data series has been 'pre-whitened' following the procedure described in Partal and Kahya (2006). The pre-whitened data series may be obtained as \( (x_2 - r_1x_1, x_3 - r_1x_2, \ldots, x_n - r_1x_{n-1}) \)

**Trend analysis**

Several tests are available for the detection and estimation of trends. In this particular study, Mann-Kendall’s test was employed. Mann-Kendall’s test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear (Partal and Kahya, 2006; Yenigun et al., 2008). The Mann-Kendall’s test statistic is given as:

\[
S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \text{sgn} (x_j - x_i)
\]

Where \( S \) is the Mann-Kendall’s test statistics; \( x_i \) and \( x_j \) are the sequential data values of the time series in the years \( i \) and \( j \) (\( j > i \)) and \( N \) is the length of the time series. A positive \( S \) value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The sign function is given as:

\[
\text{sgn}(x_j - x_i) = \begin{cases} 
+1 & \text{if } (x_j - x_i) > 0 \\
0 & \text{if } (x_j - x_i) = 0 \\
-1 & \text{if } (x_j - x_i) < 0 
\end{cases}
\]

The variance of \( S \), for the situation where there may be ties (that is equal values) in the \( x \) values, is given by:

\[
\text{Var} (S) = \frac{1}{18} \left[ N(N-1)(2N+5) - \sum_{i=1}^{m} t_i (t_i - 1)(2t_i + 5) \right]
\]

Where, \( m \) is the number of tied groups in the data set and \( t_i \) is the number of data points in the \( i \)th tied group. For \( n \)
larger than 10, Z_MK approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun et al., 2008) and computed as follows:

$$Z_{MK} = \begin{cases} 
\frac{S - 1}{\sqrt{Var(S)}} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S + 1}{\sqrt{Var(S)}} & \text{if } S < 0 
\end{cases}$$

The presence of a statistically significant trend is evaluated using the $Z_{MK}$ value. In a two-sided test for trend, the null hypothesis $H_0$ should be accepted if $|Z_{MK}| < Z_{1-\alpha/2}$ at a given level of significance. $Z_{1-\alpha/2}$ is the critical value of $Z_{MK}$ from the standard normal table. E.g. for 5% significance level, the value of $Z_{1-0.025}$ is 1.96.

The Sen’s estimator of slope: This test is applied in cases where the trend is assumed to be linear, depicting the quantification of changes per unit time. This method could be used with missing data and remain unaffected by outliers or gross errors (Karpouzos et al., 2010). The slope (change per unit time) was estimated following the procedure of Sen (1968). A detailed outline of the procedure is given in Partal and Kahya (2006) and Karpouzos et al. (2010).

Based on the earlier procedure trends of annual, seasonal (kiremt and belg) and monthly (June-September) totals as well as rainfall characteristics such as onset date, cessation date, LGP, number of rainy days and dry spell length were determined. Therefore, the rainfall characteristics of each station were first set as follows:

Onset and cessation date: Different authors use different threshold values to determine the onset 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 July first) with no dry spell greater than 7 days in the next 30 days (Teschaye and Walker, 2004). Moreover, 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 (Teschaye and Walker, 2004) after September 11. This date was set based on farmers’ information obtained during preliminary survey. The length of growing period was calculated as a difference between the onset date and date of the end of the season.

Number of rainy days and dry spell length: Based on the definition of National Meteorological Service Agency of Ethiopia, a day is considered as a rainy day if it accumulates 1 mm or more rainfall (NMSA, 2001). The number of rainy days was, therefore, counted starting from the first day of June to September 30 (kiremt season) in each year. Moreover, maximum number of consecutive dry days (a day that accumulate rainfall <1 mm) were counted to determine dry spell length in kiremt season.

Variability analysis

Standardized anomaly index, precipitation concentration index and coefficient of variation were used as descriptors of rainfall variability (Bewket and Conway, 2007; Ayalew et al., 2012).

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. This index is used to examine the nature of the trends and enables the determination of the dry and wet years in the record. Its formula is given as:

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

Where, $Z$ is standardized rainfall anomaly; $x$ is the annual rainfall total of a particular year; $\mu$ is mean annual rainfall over a period of observation and $\delta$ is the standard deviation of annual rainfall over the period of observation.

Precipitation Concentration Index (PCI) was analyzed using DeLu’s et al. (1999), which is the modified version of Oliver’s (1980). It was computed as follows:

$$PCI = \frac{12}{\sum i=1} \frac{P_i^2}{\left(\sum_{i=1}^{12} P_i^2\right)^{1/2}} \times 100$$

Where, $P_i$ is the rainfall amount of the $i^{th}$ 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 very high concentration of monthly rainfall distribution.

Coefficient of variation (CV) was calculated to evaluate the variability of the rainfall and its characteristics by dividing the standard deviation of the event to its mean.

Farmers’ perception

To compare meteorological data with the perception of farmers at the ground, survey was conducted in three different woredas (administrative unit equivalent to district) of Tigray region. During the study, three districts having long term meteorological data records were selected purposively. Similarly, two peasant associations (the smallest administrative unit) neighboring the meteorological stations, from each district were again purposively selected. In the third stage, a total of 253 farm households was sampled randomly proportional to the
RESULTS AND DISCUSSION

Annual and seasonal rainfall regimes

Rainfall in the study area is generally low that varies slightly from 509 mm at Adigudum to 752 mm at Alamata (Table 2). The main rainy season (kiremt rainfall) contributes largely to the annual rainfall totals in all stations. However, its contribution varies from 50-90% depending on the site of the location. Belg rainfall also makes a considerable contribution to the annual rainfall totals in some areas such as Adigrat (29%), Edagahamus (31%) and Alamata (36%). Similarly, in the Amhara regional state of Ethiopia, kiremt and Belg rainfall had contributed 55-85% and 8-24%, respectively to the annual rainfall totals (Bewket and Conway, 2007; Ayalew et al., 2012).

The coefficient of variation in most stations revealed that rainfall in the region has high inter-annual variability (Table 3). The result indicated that annual rainfall at Adigudum (CV>40%) and at Edagahamus (CV>70%) was extremely variable. Moreover, kiremt rainfall variability for most stations was also high (CV nearly >30%). In contrast, Bewket and Conway (2007) reported moderate inter-annual variability of kiremt rainfall in the Amhara regional state of Ethiopia. Considering the direct effect of Kiremt rainfall on agricultural production, high variability could tremendously affect the livelihood of the farming community in the region. Likewise, Belg rainfall in the region showed high inter-annual variability (CV>50%). Comparing the seasonal variability of rainfall in the region, Belg rainfall is more variable than the kiremt rainfall. Seleshi and Zanke (2004); Bewket and Conway (2007) reported similar results. Seleshi and Zanke (2004) noted that the rainfall variability over the central highland of Ethiopia during the kiremt season was associated with the equatorial eastern Pacific sea level pressure, the southern oscillation index and the sea surface temperature (SST) over the tropical eastern Pacific Ocean. These authors further noted that the SST over the tropical eastern Pacific Ocean is negatively correlated with kiremt rainfall.

Moreover, analysis of PCI value revealed that all stations have greater than 20% (Table 3). Based on the scale defined in De Lui’s et al. (1999), the stations are grouped under high and very high concentration which indicates poor monthly distribution of the rainfall. A similar result was also indicated in Bewket and Conway (2007) and Ayalew et al. (2012) wherein the rainfall in the Amhara region of Ethiopia is characterized by high to very high monthly concentration.

Standard anomaly index (SAI): Analysis of the standard anomaly index for the stations is depicted in Figure 2. The rainfall pattern in the studied stations exhibits certain characteristics that a dry year is followed by another two or three dry years and vis-à-vis for the wet years. The study revealed that many of the stations have experienced drought during 1980s and 2000s. Generally, for the period 1980-2009, the number of years recorded below the long term average at Alamata, Adigudum, Mekelle, Edagahamus and Adigrat were 43, 47, 50, 43 and 57%, respectively. However, frequency occurrence of below normal rainfall has been increased in the last decade. In this regard, 60% of the years in the recent decade had recorded below long term average in all stations. Moreover, during the last 30 years, 1984 was the driest years at Alamata, Edagahamus and Mekelle while for Edagahamus and Adigrat it was 1990 and 1999, respectively. Bewket and Conway (2007) and Ayalew et al. (2012) had used SAI to demonstrate the intensity and frequency of drought at various time scales and reported as helpful to indicate the drought characteristics.

Trend analysis of rainfall elements

Annual and seasonal rainfall trends: The Mann–Kendall trend test shows a decreasing trend of annual rainfall in most of the stations (Table 4). In the last three decades, at the stations of Alamata, Adigudum, Mekelle and Edagahamus, annual rainfall had decreased by 43.8, 141.9, 158.7 and 143.4 mm, respectively. The station of Adigrat, on the other hand, had indicated an increasing trend of annual rainfall. However, both increasing and decreasing trends of annual rainfall totals were not statistically significant. This might be due to large inter-annual fluctuation of rainfall in the region. For instance, at Alatama and Adigrat the 1980s were generally a dry period relative to preceding decade and rainfall has recovered to more humid conditions during the 1990s that again decreased to below long term average in the 2000s (Figure 2). Thus, analysis that ends during the late 1980s or early 1990s might show a declining trend, whereas if the period is extended, the trend in annual rainfall totals could reduce and/or removed. On the other hand, rainfall at Mekelle, Adigudum and Edagahamus shows consecutive 2–3 year periods with wet and dry years alternatively with no apparent trend. This result agrees with the findings of Conway (2000), Seleshi and Zanke (2004), Cheung et al. (2008) and Viste et al. (2012) that indicates non-significant trend of annual and seasonal rainfall totals in northern Ethiopia.
Table 2. Average seasonal rainfall contributions to annual rainfall totals in Northern Ethiopia, 1980-2009.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Annual rainfall (mm)</th>
<th>Kiremt rainfall (mm)</th>
<th>Belg rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alamata</td>
<td>752</td>
<td>377 (50%)</td>
<td>270 (36%)</td>
</tr>
<tr>
<td>Adigudum</td>
<td>509</td>
<td>454 (89%)</td>
<td>46 (09%)</td>
</tr>
<tr>
<td>Mekelle</td>
<td>601</td>
<td>487 (81%)</td>
<td>97 (16%)</td>
</tr>
<tr>
<td>Edagahamus</td>
<td>687</td>
<td>423 (62%)</td>
<td>216 (31%)</td>
</tr>
<tr>
<td>Adigrat</td>
<td>584</td>
<td>364 (62%)</td>
<td>171 (29%)</td>
</tr>
</tbody>
</table>

Percentage contribution to annual rainfall is given in parentheses.

Table 3. Coefficient of variation for annual, kiremt and belg rainfall and mean PCI values for the period 1980–2009 in Northern Ethiopia.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Annual</th>
<th>Main rain season</th>
<th>Small rain season</th>
<th>PCI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alamata</td>
<td>0.29</td>
<td>0.49</td>
<td>0.69</td>
<td>21</td>
</tr>
<tr>
<td>Adigudum</td>
<td>0.43</td>
<td>0.49</td>
<td>0.71</td>
<td>32</td>
</tr>
<tr>
<td>Mekelle</td>
<td>0.26</td>
<td>0.29</td>
<td>0.75</td>
<td>30</td>
</tr>
<tr>
<td>Edagahamus</td>
<td>0.73</td>
<td>0.75</td>
<td>1.04</td>
<td>23</td>
</tr>
<tr>
<td>Adigrat</td>
<td>0.25</td>
<td>0.28</td>
<td>0.52</td>
<td>21</td>
</tr>
</tbody>
</table>

PCI is precipitation concentration index.


<table>
<thead>
<tr>
<th>Stations</th>
<th>Annual</th>
<th>Kiremt season</th>
<th>Belg season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ZMK</td>
<td>slope</td>
<td>ZMK</td>
</tr>
<tr>
<td>Alamata</td>
<td>-0.32ns</td>
<td>-1.46</td>
<td>1.04ns</td>
</tr>
<tr>
<td>Adigudum</td>
<td>-1.18ns</td>
<td>-4.73</td>
<td>-1.07ns</td>
</tr>
<tr>
<td>Mekelle</td>
<td>-1.53ns</td>
<td>-5.29</td>
<td>-1.25ns</td>
</tr>
<tr>
<td>Edagahamus</td>
<td>-1.14ns</td>
<td>-4.78</td>
<td>0.21ns</td>
</tr>
<tr>
<td>Adigrat</td>
<td>0.07ns</td>
<td>0.16</td>
<td>-0.36ns</td>
</tr>
</tbody>
</table>

ZMK is Mann–Kendall trend test. Slope (Sen’s slope) is the change (mm)/annual; ns is non-significant trend at 0.05 and 0.1 and * indicates significant trend at 0.1 significant level.

Likewise, stations of Adigudum, Mekelle and Adigrat had revealed a decreasing trend of kiremt rainfall totals while Alamata and Edagahamus had shown an increasing trend. Moreover, all stations during belg season showed decreasing trend (Table 4). Especially, the negative trend at Alamata and Edagahamus was statistically significant at 10% probability level. Overall, the direction and magnitude of the seasonal rainfall trend was not uniform. Bewket and Conway (2007) and Ayalew et al. (2012) had also reported similar results, wherein the direction and magnitude of the trend in seasonal rainfall in Amhara regional state of Ethiopia varies from station to station. The major driving factors that influence rainfall patterns in Ethiopia are the equatorial eastern Pacific sea level pressure, the southern oscillation index and the sea surface temperature (SST) over the tropical eastern Pacific Ocean (Seleshi and Zanke, 2004). However, within the regions of Ethiopia, rainfall is governed with elevation (Conway, 2000). This inconsistent trend of the stations might also be the main reason for these studies that reported non-significant trend of annual and seasonal rainfall over the country in general and in the region in particular.

Monthly rainfall trends: Considering rainfall during months of the main growing season (June to September), decreasing trends had observed at Adigudum in all growing months (Table 5). Likewise, except the month of June, rainfall at Mekelle also revealed a decreasing trend in all months of the growing season. On the other hand, despite the variability of the stations with regard to the magnitude and direction of trends, a negative trend had observed in all stations during the month of September. This indicates contraction of the LGP and increase in terminal drought. However, neither of the trends was statistically significant.
Table 5. Trends of monthly (June-September) rainfall totals in northern Ethiopia for the period 1980-2009.

<table>
<thead>
<tr>
<th>Stations</th>
<th>June $Z_{MK}$</th>
<th>July $Z_{MK}$</th>
<th>August $Z_{MK}$</th>
<th>September $Z_{MK}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alamata</td>
<td>0.51**</td>
<td>1.11**</td>
<td>1.34**</td>
<td>-0.14**</td>
</tr>
<tr>
<td>Adigudum</td>
<td>-0.98**</td>
<td>-0.71**</td>
<td>-0.57**</td>
<td>-0.54**</td>
</tr>
<tr>
<td>Mekelle</td>
<td>0.87**</td>
<td>0.44</td>
<td>-0.61**</td>
<td>-0.92</td>
</tr>
<tr>
<td>Edagahamus</td>
<td>-0.71**</td>
<td>1.18**</td>
<td>0.71**</td>
<td>-1.02**</td>
</tr>
<tr>
<td>Adigrat</td>
<td>0.05**</td>
<td>0.01</td>
<td>-0.96**</td>
<td>-0.33**</td>
</tr>
</tbody>
</table>

$Z_{MK}$ is Mann-Kendall trend test, Slope (Sen’s slope) is the change (days)/annual; ns is non-significant trend at 0.05 and 0.1.

Table 6. Statistical characteristics and trends of onset date, cessation date and LGP at five stations over the period 1980-2009 in Northern Ethiopia.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Onset date Median</th>
<th>Cessation date Median</th>
<th>LGP (days) Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alamata</td>
<td>Jul-4</td>
<td>Sep-21</td>
<td>79</td>
</tr>
<tr>
<td>Adigudum</td>
<td>Jul-12</td>
<td>Sep-20</td>
<td>71</td>
</tr>
<tr>
<td>Mekelle</td>
<td>Jul-11</td>
<td>Oct-4</td>
<td>85</td>
</tr>
<tr>
<td>Edagahamus</td>
<td>Jul-3</td>
<td>Sep-8</td>
<td>66</td>
</tr>
<tr>
<td>Adigrat</td>
<td>Jul-5</td>
<td>Sep-16</td>
<td>74</td>
</tr>
</tbody>
</table>

$Z_{MK}$ is Mann-Kendall trend test, Slope (Sen’s slope) is the change (days)/annual; **,* is statistically significant at 0.05 and 0.1 probability level; ns is non-significant trend at 0.1; SD is standard deviation; CV is coefficient of variation.

Trends in long term characteristics of kiremt rainfall

**Onset date**: The median for onset of kiremt rainfall is similar in all stations and it begins on the first week of July (Table 6). It was also characterized with high standard deviation (> 10 days). This high standard deviation, particularly at Alamata and Edagahamus, implies that patterns could not be easily understood and consequently decisions pertaining to crop planting and related activities should be taken with great care. Furthermore, the result also indicated that the onset date in the last 30 years was significantly changed in most stations. In this regard, the rain at Alamata, Adigudum, Mekelle, Edagahamus and Adigrat has come on average 3-7 days late per decade. On the other hand, Araya and Stroosnijder (2011) had presented similar result that the onset of kiremt rainfall at Alamata, Adigudum, Maichew and Mekelle was the first decade of July.

**Cessation date**: Kiremt rainfall in the studied stations has ceased starting from the first week of September (at Edagahamus) to first week of October (at Mekelle) (Table 6). Araya and Stroosnijder (2011) had also reported similar findings in northern Ethiopia. The result further indicated that kiremt rainfall has ceased early in the northeast part of the region as compared to the south and southeast parts. The median date of the end of the kiremt season had characterized by low standard deviation (<10 days) at Adigudum, Mekelle and Adigrat and hence the end of rainy season in these stations is relatively stable. In contrast, end of the kiremt season at Alamata and Edagahamus showed high standard deviation (about 20 days), which implies difficulty in understanding of the pattern of end of the rainy season. Hence, decisions related to terminal drought management practices and crop harvesting activities requires great care. Moreover, a decreasing trend has been observed in cessation of kiremt rainfall in most stations.
Particularly, the trend at Adigudum and Mekelle was statistically significant. In contrast, an increasing trend of Kiremt rainfall cessation has been observed at Edagahamus.

**Length of growing period (LGP):** Average length of growing period in the study region varies from 66-85 days depending on the location of the station (Table 6). Mekelle and Alamata had respectively, 85 and 79 days of LGP as compared to Edagahamus, which had only 66 days. The coefficient of variation at Alamata (28%) and Edagahamus (29%) also showed high year to year variability of LGP. In contrast, Adigudum, Mekelle and Adigrat had recorded low coefficient of variation (<20%) in LGP, which can help to plan the type of crops grown based on their maturity period. On the other hand, all stations revealed that LGP has become reduced in the last three decades. The decreasing trend in LGP at Alamata, at Adigudum, at Mekelle and at Adigrat was statistically significant. Based on the present result, for the period (1980-2009), LGP was decreased by 27.6, 25.8, 24.3 and 13.2 days, respectively for Alamata, Adigudum, Mekelle and Adigrat. Correlation analysis of LGP with onset date and end of rainy date showed a strong relationship in all stations (data not showed). The short LGP at Edagahamus is, therefore, resulted due to early cessation of rainfall in the area.

**Number of rainy days:** Average number of annual rainy days and maximum dry spell length observed in kiremt season at five stations over the period 1980-2009 is depicted in Table 7. The number of annual rainy days observed in the study region varies from 50 days (at Adigudum) to 66 days (at Alamata). In line with this, the number of annual rainy days at Mekelle was 61 days and its trend was non-significant over the period 1965-2002 (Seleshi and Zanke, 2004). In regard to the inter-annual variability, number of rainy days recorded at Alamata, Adigudum and Edagahamus had observed higher variability (CV=20%) as compared to other stations. On the other hand, the Mann-Kendall’s trend test in the number of rainy days indicated that most stations revealed decreasing trend. The trend at Alamata was significant, which decreased by 6.8 days per decade. However, the number of rainy days at Mekell had increased by 1.5 days per decade. Seleshi and Zanke (2004) had also reported non-significant trend of rainy days from ten stations in Ethiopia.

**Dry spell length:** The average length of dry spell during the kiremt season over the region was generally long that ranged from 21 days at Mekelle to 26 days at Alamata and Edagahamus (Table 7). It has been indicated that the average length of dry spell during kiremt season had a low standard deviation (<10 days) in most of the stations studied (Table 7). This implies that the occurrence of a dry spell length indicated at each station during the kiremt season at least once is certain. The result further revealed that the dry spell length during kiremt season has shown an increasing trend in all stations. The trend was statistically significant for most stations. Hence, it could be helpful to devise agronomic practices that retain moisture at the plant root zone and reduce crop failure due to extended dry spell. Seleshi and Camberlin (2006) also reported similar results that longer dry spell was observed in the northern (Mekelle 20.3 days) and eastern (JJiga 16.2 days) part of the country.

Under dryland conditions where interannual and interseasonal variability of rainfall is high, analysis of trends in rainfall events such as onset, cessation, LGP, dry spell length and number of rainy days might be more important than annual and seasonal totals.

**Perception of farmers on annual and seasonal rainfall trends**

Perception of farmers on trends and variability of seasonal
and annual rainfall totals and its distribution is presented in Table 8. The results showed that more than 92% of the farmers at Adigrat perceived a decreasing trend of annual, kiremt and belg rainfall totals. Likewise, about 73.4% of the farmers at Mekelle noticed a decrease in annual and kiremt rainfall while 71.3% perceived a declining trend of belg rainfall totals. Moreover, about 69.5, 67.1 and 70.1% of the contacted farmers at Alamata had perceived a reducing trend of annual, kiremt and belg rainfall totals, respectively. On the other hand, 25% of the farmers at Alamata perceived no change in the annual, kiremt and belg rainfall in the last 30 years. This result is in line with the findings of Deressa et al. (2009) and Mengistu (2011) who reported that farmers in northern Ethiopia perceived changes in the amount and timing of precipitation.

However, the perception of farmers’ that indicate decreased trend of annual and seasonal rainfall totals did not agree with observed meteorological data of the area, which shows non-significant trend in all stations (Table 8). This contradicts with that of Ovuka and Lindqvist (2000). This discrepancy could be evolved due to the fact that rainfall amount received during the recent years was below the long term average (Figure 2). These years are fresh to remember by the farming community and hence influence their perception. In addition, as mentioned earlier, the year to year variability of the annual and seasonal rainfall is very high at all stations studied. This could remove the significant trend in meteorological data but leads to recurrent drought and production loss, which might in turn affect the farmers’ perception. Similar to the result of the present study, Meze-Hausken (2004) and Deressa et al. (2009) reported that most farmers noticed changes in the amount and occurrence of rainfall in their locality yet the observed climate data did not indicate a significant trend in Northern Ethiopia.

Although most farmers in the region perceived change in annual and seasonal rainfall totals, there was considerable difference among the stations. In this aspect, more than 90% of the farmers at Adigrat had perceived decrease in annual and seasonal rainfall totals while less than 70%
perceived at Alamata. As indicated in Figure 2, the relative frequency of negative rainfall anomalies at Adigrat was higher than at Alamata and Mekelle. This might be the reason for the difference in farmers’ perception on changes in annual rainfall totals in these stations.

Perception of farmers on trends of onset, cessation dates and the LGP

Farmers in the study area perceived that rainfall events such as onset date, cessation date and LGP have been
changed (Table 8). It has been indicated that more than 97% of the farmers at Adigrat had perceived increasing late onset and early cessation of kiremt rainfall and consequently, 100% believed decreased in LGP. Moreover, about 91.5 and 71.8% of farmers at Mekelle had noticed an increase in frequency of late onset and early cessation in kiremt rainfall, respectively while more than 87% perceived decrease in LGP. About 75 and 68% of the contacted farmers at Alamata perceive the increased rate of late coming and early withdrawal of kiremt rainfall, respectively and about 68% of the farmers perceives decreased LGP.

The perception of farmers on kiremt rainfall characteristic events such as onset date, cessation date and LGP has been supported with observed meteorological data of the stations. In this regard, perception of farmers’ on increase in frequency of late onset of kiremt rainfall and subsequent reduction in LGP was agreed with observed data at Adigrat, Alamata and Mekelle. However, the perception of farmers’ on early withdrawal of kiremt rainfall was agreed with observed data only at Mekelle. Kemausuor et al. (2011) and Nyanga et al. (2011) reported that farmers in Ghana and Zambia respectively perceive rainfall timing had changed, resulting in increased frequency of drought.

Conclusions

Detection of trends using nonparametric methods, including Sen’s method and the Mann-Kendall test, showed a decline in annual and seasonal rainfall amounts, but these trends were found to be statistically non-significant (P>0.05) at most of the stations studied. This disagrees with the perception of local people, which confirms changes in the form of reduction in annual, kiremt and belg rainfall amounts. On the other hand, rainfall events such as onset and cessation date, length of growing period and dry spell length have shown significant trends. Likewise, the local people also noticed an increase in frequency of late onset and early cessation of the rain and shortening of the LGP. In conclusion, climate change is apparent in the region, which dominantly expressed in terms of kiremt rainfall onset, cessation date, LGP, dry spell length and number of rainy days. Furthermore, most stations were experiencing a moisture deficit and drought conditions in the last decade. If the same trend continues in the future, more chances of drought are expected. Therefore, some form of coping mechanism both at community and government levels should implement to reduce the impact, which arising from it.

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