Rainfall and Temperature Trend Analysis at Indibir Station, Gurage Zone, Ethiopia

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Abstract
In Ethiopia where crop production overly depends on rainfall and temperature, studying the trend of these climate variables at a local scale is essential to devise proper strategies that enhance adaptive capacity. In light of this, a study was conducted in Indibir station, Gurage Zone to analyze rainfall and temperature trend. Data on climate variables (1986-2015) were obtained from National Meteorological Agency of Ethiopia. Mann-Kendall test was used for the analysis of trend in rainfall and temperature from 1986 to 2015 time period and carried out by XLStata softwares. The analyzed data indicated the respective annual and kiremt rainfall amounts were found to increase by a factor of 4.5 and 6.15 mm/year. However, the seasonal belg rainfall amount decreased by -2.23 mm/year and it was not statistically significant for the study period of 1986 to 2015. Respective annual and belg maximum temperature showed an increasing trend by a factor of 0.03 and 0.06 OC/year, but a decreasing trend was observed in kiremt maximum temperature by -0.13 OC/year. Minimum temperature revealed a decreasing trend at annual, belg and kiremt seasons by a factor of -0.2, -0.16 and -0.1 OC/year, respectively. Development planners of the area should design strategies and plans by taking into account a declining belg rainfall and increasing temperature impacts on livelihood of local communities.

1. Introduction

According to the NMA (2007) average annual rainfall trends remained more or less constant between 1951 and 2006, whereas seasonal rainfall exhibited high variability. (Senait*et al*., 2010) there is considerable decline in rainfall from March-September in north and southeast and southwestern parts of Ethiopia after 1997. In particular, rainfall amounts have significantly decreased during the *belg* season in the east and southeast. In much of Ethiopia, similar to the Sahelian countries to its west, rainfall from June-September contributes the majority of the annual total, and is crucial to Ethiopia's water resource and agriculture operations (Diriba and Anthony, 2007). As per Misgina and Simhadri (2015a) *kiremt* rainfall in lowlands increased significantly by a factor of 106mm/decade, whereas highlands experienced non-significant change. Besides, when the highlands lose a significant amount of *belg* rainfall (35 mm/decade), lowlands didn't.

Regarding seasonal rainfall variability in Southern Ethiopia, Alaba, Angacha, Butajira, Durame, Fonko, Hossana and Wulberagshowed an increasing trend in the *kiremt* seasonal rainfall, while the other two stations (Shone and Wolkite) have shown a decreasing trend over study period of (1983-2012) (Negash and Eshetu, 2016). During *belg* season, only three stations (Alaba, Fonko and Wolkite) showed an increasing trend while the other six stations revealed a decreasing trend. Negash and Eshetu (2016) reported that high variability in annual rainfall in the region is also indicated by the variations in trend of rain with highly decreasing in Chidastation (-16.08mm/year) to highly increasing trend in Butajira station (6.26mm/year). Abiy *et al*. (2014) reported that annual rainfall showed an increasing trend by 3.93 mm/year in Indibir station over the study period of 1982-2012. Negash and Eshetu (2016) indicated that the northeast parts of Ethiopia (Wolkite, Butajira, Hossana, Bele, Indibir and Billate) are stable or not suffering from negative trend, the southern parts (Gato, Burji and Sawla) as well as south eastern part(Fisagenet and Hagereselam) of the region sufferadeclining trend of annual rainfall.
Different studies conducted in Ethiopia showed both an increasing and a decreasing trend in annual, *belg* and *kiremt* rainfall, for instance, the study conducted at Tigray region by Gebre *et al*. (2013) a declining trend in annual and seasonal rainfall amounts, but the trends did not significant at most of the stations. Woldeamlake and Conway (2007) annual and *kiremt* rainfall showed significant increasing trend at Dessie and Labella whereas significant decreasing trend was observed at Debre Tabor for the study period of 1975-2003. Woldeamlake (2009) in his study of rainfall variability and crop production in the Amhara region, he found an increasing annual and *kiremt* rainfall in Dessie and Lalibela weather stations. The same study indicated a drop in Debretabor (*kiremt)* and Dangla (*belg* rains) in the central west during the period 1975-2003. Similarly, Dereje *et al.* (2012) also found positive *kiremt* rainfall trends at Bahirdar, Gondar, Srinka, and Mettema stations, whereas

negative trends of *belg* rainfall were identified at Kombolcha and Srinka.

Measurements of minimum temperature for the period 1951-2005 indicated that the country has experienced both warm and cool years. However, recent years are in the warming front compared to the early years, increasing by about 0.37 ^{O}C every ten years (NMA, 2007). Study carried out by the UNDP climate change profile for Ethiopia (2011) also showed that the mean annual temperature increased by 1.3 ^{O}C between 1960 and 2006. The temperature increase has been most rapid from July-September (0.32 ^{O}C per decade).

Awetahegn (2015) in Tigray region found that an increasing trend or a positive trend in the annual maximum temperature by 0.018 ^{O}C per year, but negative trend was observed in minimum temperature by -0.038 ^{O}C per/year for period of record (1995-2014). Solomon *et al*. (2015) come across with an increasing trend in annual maximum and minimum temperature at Lake Tana by a factor of 0.141 ^{O}C and 0.423 ^{O}C per year respectively. USAID (2015) technical report on climate variability and change in Ethiopia reported that maximum temperatures during *kiremt* season varies between 0.4-0.6 ^{O}C/decade in Amhara, Oromia, Afar and Tigray region. *Belg* season temperatures showing more rapid increases (> 0.6 ^{O}C/decade) in all region. An increasing trend in annual maximum temperature by 0.44 ^{O}C, whereas minimum temperature decreased by -0.12 ^{O}C per year at Butajira station (Belay *et al*., 2014). Analysis of rainfall and temperature trend is helpful in rain-fed agriculture to devise site-specific adaptation responses against to climate risks. The aim of this study is to estimate rainfall and temperature trends at Indibir station. To be able attain expected result we conduct a thorough examination of climatic data from 1981-2015 to detect trends of rainfall and temperature at various time scales. The main purpose of this study is to analyze monthly, seasonal and annual rainfall and temperature trend and rainfall anomaly at Indibir meteorological station.

2. Methodology

2.1. Description of the Study Area

2.1.1. Location

The study was conducted at Indibir station, Gurage zone of SNNPRS, Ethiopia. The geographical coverage of the study area is 8° 17' 22.6 " N and 37° 46' 55.98" E at an elevation ranging from 1050 to 1883m.a.s.l.

2.2.1. Rainfall and temperature data

The data used for this study were archival data on rainfall, temperature from NMA. Data on daily rainfall and temperature were collected for 30 years (1986-2015). The choice of the time series is in line with the convention of using 30 years weather data in characterizing the climate of an area, as adopted by the WMO. Indibir weather station is one of the principal station in Ethiopia and records all type of climatic parameters including temperature and rainfall within 50-100 km radius. Rainfall and temperature data were captured in to Microsoft excel 2013 spreadsheet following the day of year (DOY) entry format.

2.2.2. Missing value estimation

Missing data can complicate meteorological research analysis, which may be due to the absence of observer, short disturbances in observations due to breakage, malfunction and calibration problem of instruments during a certain time period, therefore need to solve before goes to further analyses. In this study, about 0.85% of daily rainfall data were missing from years of 1987, 1999, 1998 and 2001, about 0.99% of daily maximum temperature were missing from 1987, 1999 and 2001 and about 0.6% of daily minimum temperature were missing from 1987, 1992, 1995, 2001, and 2003 during observation year (1986-2015). Hence, the missing values were patched using first order Markov chain model of Instat version 3.37 software.

2.2.3. Rainfall data consistency

The consistency of the rainfall data set was checked by the single mass-curve method and a plot of cumulative annual rainfall data against time (Appendix Figure 1). The single mass curve was plotted by using the annual cumulative total rainfall of the Indibir station as ordinate(y) and the years of data/observation as abscissa(x) (1986-2015).

2.2.4. Homogeneity test

Data homogenization is defined as means the removal of non-climatic changes. Next to changes in the climate itself, raw climate records also contain non-climatic jumps and changes for example due to relocations/changes in instrumentation. For this study, Buishand's homogeneity testing (1982) method was used to check data homogeneity. The basic statistics associated with this test are summarized in Appendix Table 1 for all important climatic parameters considered in this study. The test of homogeneity of the rainfall and temperature data series based on the hypothesis made, the computed *P*-values of rainfall and maximum temperature were found to be greater than the significance level (alpha = 0.05), hence the annual rainfall and maximum temperature data series revealed trendless and can be concluded that data was homogenous. Conversely, minimum temperature was found to be less than the significance level (alpha= 0.05), thus the minimum temperature data revealed trend in the series and can be concluded the data series was not homogenous.

2.2.6. Analysis of rainfall and temperature trend

Mann-Kendall test was used for the analysis of trend in rainfall and temperature from 1986 to 2015 time period.

There are two benefits of using Mann-Kendall test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. Each data value is likened to all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time, the statistic *S* is increased by 1. On the other hand, if the data value from the later time period is lower than a data value sampled earlier, *S* is decreased by 1. The net result of all such increments and decrements is one that determines the final value of S. The Mann-Kendall S Statistic is mathematically computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\,(T_j - T_i)_{(2)}$$

$$Sign\,(T_j - T_i) = \begin{cases} 1\ if\ T_j - T_i > 0 \\ 0\ if\ T_j - T_i = 0 \\ -1\ if\ T_j - T_i < 0 \end{cases}$$

Where T_j and T_i are the monthly, seasonal and annual values in years j and i, j > i respectively.
A positive value of S indicates an increasing trend whereas a negative value indicates a declining trend in the data. At certain probability level H_0 is rejected in favor of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2,}$ where $S_{\alpha/2}$ is the smallest S which has the probability less than α/2 to appear in case of no trend. For n ≥ 10, the statistic *S* is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0$$

The variance (σ^2) for the S-statistic is defined by:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18}$$

In which t_i denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Z_s is calculated as follows

$$Z_s = \begin{cases} \frac{S-1}{\sigma} for\ S > 0 \\ 0\ for\ S = 0 \\ \frac{S+1}{\sigma} for\ S < 0 \end{cases}$$

The test statistic Z_s is used a measure of significance of the trend. In fact, this test statistic is used to test the null hypothesis, $H_{o.}$ If | Z_s| is greater than $Z_{\alpha/2}$, where α represents the chosen significance level then the null hypothesis is rejected implying that the trend is significant.

Another statistic obtained on running the Mann-Kendall test is Kendall's tau, which is a measure of correlation and therefore measures the strength of the relationship between the two variables. In common with other measures of correlation, Kendall's tau will take values between ±1 and +1, with a positive correlation indicating that the ranks of both variables increase together whilst a negative correlation indicates that as the rank of one variable increases, the other decreases. XLSTAT 2016 software was used for analyzing trend in annual, seasonal and monthly rainfall and temperature.

2.2.7. Analysis of rainfall anomaly

Standard rainfall anomalies was plotted against time (in years) to visualize the time series variation of annual and seasonal rainfall with the mean. The Standardized Anomaly Index (SAI) was calculated as the difference between the annual/seasonal totals of a particular year and the long term average rainfall records divided by the standard deviation of the long term data. This index was used to observe the nature of the trends and also enables the determination of the dry and wet years in the record. Mathematically computed as:

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

Where, Z is standardized rainfall anomaly; x is the annual/seasonal rainfall total of a particular year; μ is mean annual/seasonal rainfall over a period of observation and δ is the standard deviation of annual/ seasonal rainfall over the period of observation.

3. RESULT AND DISCUSSION

3.1. Seasonal and annual total rainfall and number of rainy days

The annual rainfall amount for the study area ranged from 309.8 mm to 1738.4 mm, while *belg* and *kiremt* rainfall amount varied from 99.55 mm to 481.3 mm and 162.7 mm to 1202 mm respectively (Table 1). There is moderate variation (CV= 24.2%) in annual rainfall amount with a mean of 1182.2 mm and SD of 286.57 mm. Similarly, there is moderate variation (CV=27.4 %) in *kiremt* amount of rainfall and a mean of 796.4 mm with SD of 217.9 mm. Highly variable condition (CV =39.5%) in *belg* rainfall was observed with a mean and SD of 282.3 mm and 111.4 mm, respectively. According to NMA (2007) farmers in Ethiopia are totally dependent on *kiremt* rainfall for their crop production and a small fluctuation in the rainfall amount, intensity, duration, onset days and cessation days directly impacts the agricultural activities. *Belg* rainy season (CV=42%) in southern

Tigray is highly variable than the *kiremt* one (CV=24%) (Misgina and Simhadri, 2015b). Abiy *et al*. (2014) reported that the mean annual, *belg* and *kiremt* total rainfall of 1270.7 mm, 288.1 mm and 844.4 mm were registered at Wolikte station respectively.

The highest *belg* rainfall total amount was 481.3 mm in 2010, whereas the lowest being was 99.5 mm in year 2000. The maximum *kiremt* rainfall total amount was 1202 mm which occurred in year 2011, whereas the minimum *kiremt* rainfall amount was 263.6 mm occurred in year 1992. High CV was observed for *belg* rainfall amount than *kiremt* and annual rainfall (Table 1). Therefore, based on Hare (2003) classification, the study area has been vulnerable to drought during *belg* season (CV > 30%). *Kiremt* rainfall was relatively stable when compared to the *belg,* however, irregularity and deficiency of the rainfall of this season affects the food production of the country (NMSA,1996). According to Yilma and Ulrich (2004) *belg* season rainfall variation in the country is due to weather systems that arises from Indian Ocean. Similarly, high *belg* rainfall variability was also reported by Dereje *et al*. (2012) over the Amhara Region compared to the *kiremt* and annual total rainfall during 1979-2008. Abiy *et al*. (2014) reported that *belg* season was unreliable in Wolkite area and he found CV of 48%.

Table 1. Descriptive statistics for monthly, *belg, kiremt* and annual rainfall at Indibir station (1986-2015)

Parameters	Min	Q1 (25%)	Q2 (50%)	Q3 (75%)	Max	Mean	R^2	SD	CV (%)
Jan	0	0	5.3	27.9	103.6	18.4	0.001	17.8	96.7
Feb	0	7.5	17.95	32.05	82.3	23.17	0.26	22.14	95.6
Mar	0	24.4	42.85	77.85	166.6	58.4	0.05	50.12	85.9
Apr	0	43.5	65.55	95.1	335.6	78.98	0.03	62.23	78.8
May	11.8	60.8	109.05	155.4	251.9	118.52	0.15	68.85	58.1
Jun	27.5	131.3	178.35	203.45	351.3	172.2	0.04	69.19	40.2
Jul	40.8	199.9	250.35	278.4	565.4	241.49	0.04	91.15	37.75
Aug	43.4	195.8	243.24	285.6	519.8	242.25	0.05	95.13	39.27
Sep	27	80.03	156.73	188.78	297.6	140.49	0.06	66.02	46.99
Oct	0	14.2	60.3	81.7	185.1	61.2	0.006	51.3	83.9
Nov	0	0	1.9	21.8	100	14.3	0.08	13.6	95.1
Dec	0	0	1.4	12.6	51.5	8.9	0.03	7.3	82.1
Belg	99.5	182.8	282	368.7	481.3	282.3	0.01	111.4	39.5
Kiremt	162.7	673.1	831.4	925.7	1202	796.4	0.09	217.9	27.4
Annual	309.8	1082	1191.8	1326.2	1738.4	1182.2	0.05	286.6	24.2

Min = minimum value, Q1 (25%) = first quartile, Q2 (50%) = second quartile, Q3 (75%) = third quartile, max = maximum value, SD ($\pm$) = standard deviation, R2 = coefficient of determination, CV = coefficient of variation

In *belg* season, the number of rainy days ranged from 19 to 64 days with a mean of 37.3 days. The maximum number of rainy days during *belg* season was 64 days that was experienced in year 2010, whereas the minimum number of rainy days was 19 days which was recorded in 1994. *Kiremt* number of rainy days varied from 55 to109 days with a mean of 86.2 days (Table 2).

Table 2. Descriptive statistics for annual, *belg* and *kiremt* number of rainy days at Indibir station (1986-2015)

Descriptive statistics	Annual number of rainy days	*Belg* number of rainy days	*Kiremt* number of rainy days
N	30	30	30
Min	89	19	55
Max	191	64	109
Mean	140.8	37.3	86.2
SD	26.1	11.9	14.1
CV (%)	18.5%	31.8%	16.3%

3.1.6. Rainfall and temperature trend

3.1.6.1. Annual, seasonal and monthly rainfall trend analysis

The annual rainfall showed an increasing trend by a factor of 4.49 mm per year (Table 3). The result of annual rainfall probability value showed non- significant trend. The positive trend over the study area is not statistically significant, which might be associated to large inter annual fluctuation. According to Hulme *et al.* (2001) and IPCC (2001), East Africa rainfall shows an increasing trend. Negash and Eshetu (2016) reported decreasing trend at Chida station (16.08mm/year) and increasing trend at Butajira station (6.26mm/year). Similarly, at Indibir Abiy *et al*. (2014) observed an increasing trend by 3.93 mm/year over the study period of 1982-2012. Negash and Eshetu (2016) also have shown that annual rainfall at Alaba, Angacha, Fonko, Hossana and Wulberag stations showed an increasing trend, but at seven of the studied stations annual rainfall did not show statistically significant trend.

Table 3. Mann-Kendall trend statistics for monthly, *belg, kiremt* and annual rainfall

parameters	Years	Sen's Slope	Z value	Mk statistic (S)	*P*-value
Jan	30	-0.18	-0.04	-17	0.764
Feb	30	-1.01	-0.38	-164	0.004
Mar	30	-0.67	-0.11	-46	0.422
Apr	30	-0.62	-0.09	-37	0.524
May	30	3.17	0.27	117	0.041
Jun	30	1.17	0.13	55	0.342
Jul	30	0.5	0.05	23	0.697
Aug	30	1.58	0.14	61	0.288
Sep	30	1.84	0.15	65	0.256
Oct	30	0	0.07	27	0.715
Nov	30	0.34	0.44	160	0.002
Dec	30	0	0.07	27	0.615
Belg	30	-2.23	-0.09	-39	0.502
Kiremt	30	6.15	0.17	75	0.189
Annual	30	4.49	0.13	57	0.321

At season level, the *kiremt* rainfall showed an increasing trend by a factor of 6.15 mm per year (Table 3). However, the probability value does not reveal statistical significance (*P*=0.189). Negash and Eshetu (2016) also reported that *kiremt* seasonal rainfall shows an increasing trend in SNNPRS, although some stations show a decreasing trend. The *belg* rainfall of present study showed a declining trend by a factor of -2.23 mm per year, but it does not show statistically significance trend in the time series (Table 4). Unlike this Funk et al. (2012) found declined *belg* and *kiremt* rain in parts of Ethiopia by 15-20 percent since the mid-1970s.

Monthly rainfall is the lowest for January, February, March, April, October, November and December (0 mm) followed by May (11.8 mm) and September (27 mm), while highest monthly rainfall was registered in July (565.4 mm) followed by August (519.8 mm) and June (351.3 mm) (Appendix Table 5). Monthly SD and CV of rainfall varied from 7.3 to 95.13 mm and 37.75 to 96.7% respectively (Table 1). The proportion of variation in monthly rainfall explained by the year was varied from 0.1-26%. The monthly rainfall from January to April showed a decreasing trend, but positive trends were observed in May, June, July, August, September and November. As a result, the rain-fed dependent agrarian population of the area suffers water shortage for their crop, livestock and for household consumptions. Monthly rainfall did not reveal statistically significant trend at ($P\leq0.05$) in March, April, June to October and December, but February, May and November showed statistically significant trend (Table 3). According to Belay *et al*. (2014), annual and *kiremt* rainfall showed an increasing trend by 0.01 and 1.95 mm/year respectively, but *belg* rainfall showed a decreasing trend by -1.53 at Butajira station over the study period of 1975-2009. According to Monadjem and Perrin (2003) rainfall trends are crucial to optimize the spatial distribution and adaptability of different agricultural enterprises.

3.1.6.2. Annual, seasonal and monthly maximum temperature trend

The year-to-year variation of annual maximum temperatures expressed in terms of temperature variability over the last 30 years at Indibir weather station as shown in Table 4. The annual maximum temperature varied between 23.35 and 29.02 ^{O}C and mean annual average maximum temperature over the study area was 27.03 ^{O}C. The annual CV and SD for maximum temperature were 4.1% and 1.16 ^{O}C respectively. The proportion of variation in annual maximum temperature explained by the time was 6% (Table 4).

The result from the Mann-Kendall analysis on annual maximum temperature showed an increasing trend by a factor of 0.03 ^{O}C per year (Table 5). The positive value of Sen's Slope for annual minimum temperature is an indication of increasing trend, which might be associated with global warming and climate change. The most likely explanation for the temperature increase might be carbon dioxide and other heat trapping "greenhouse" gases that human activities produce. However, the annual maximum temperature did not reveal a statistically significant trend at $P\leq 0.05$, which is not in agreement with the rate of global warming, estimated at 0.6 ^{O}C for the past century. According to IPCC (2007) rise in temperature will distress crops and plants require more water to replenish loss in the form of irrigation. World Bank (2011) reported that the mean annual temperature increased by the rate of 0.28 ^{O}C per decade between 1960 and 2006. Ekpoh and Nsa (2011) have argued that anthropogenic climate change may increase the likelihood of such events occurring. Belay *et al*. (2014) also found out an increasing trend in annual maximum temperature by 0.44 ^{O}C at Butajira station for the study period of 1975-2009.

Table 4. Descriptive statistics for monthly, *belg, kiremt* and annual maximum temperature at Indibir station (1986-2015)

Parameters	Min	Q1 (25%)	Q2 (50%)	Q3 (75%)	Max	Mean	R^2	SD	CV(%)
Jan	24.3	25.9	27.2	28.5	32.2	27.3	0.07	1.81	6.6
Feb	23	24.99	27.05	30	32.94	27.4	0.43	2.83	10.3
Mar	25.22	27.09	28.04	29.08	34.31	28.3	0.01	1.75	6.2
Apr	24.58	26.29	27.75	28.93	33.62	27.7	0.02	1.81	6.5
May	22	27	27.39	28.14	31	27.4	0.04	1.72	6.3
Jun	22.1	23.33	24.41	25.27	29.29	24.8	0.23	1.83	7.4
Jul	20.5	21.76	23.16	24.44	28.73	23.5	0.19	2.27	9.7
Aug	20.5	22	23.15	24.84	28.63	23.5	0.29	2.12	9
Sep	21.31	22.71	24.48	25.71	29.12	24.5	0.29	2.09	8.5
Oct	23.8	24.6	26.1	27.5	29.1	26.2	0.4	1.62	6.2
Nov	23.7	25.6	26.8	28.6	30.9	26.9	0.3	1.8	6.7
Dec	24.4	25.3	26.6	28.6	31.4	27.1	0.11	1.9	7
Belg	24.5	26.95	27.82	28.32	32.47	27.69	0.22	1.42	5.1
Kiremt	21.55	22.61	23.59	24.94	28.79	24.06	0.27	1.99	8.3
Annual	23.35	26.63	27.06	27.69	29.02	27.03	0.06	1.16	4.1

Min = minimum value, Q1 (25%) = first quartile, Q2 (50%) = second quartile, Q3 (75%) = third quartile, max = maximum value, SD ($\pm$) = standard deviation, *p*-value = probability value, R^2 = coefficient of determination, CV = coefficient of variation

At the seasonal level, the *kiremt* maximum temperature varied between 21.55 to 28.79 ^{O}C and *kiremt* average maximum temperature was 24.06 ^{O}C. *Kiremt* maximum temperature CV and SD were 8.3% and 1.99 ^{O}C respectively. The proportion of variation in *kiremt* maximum temperature explained by the year was 27% (Table 4). The *kiremt* maximum temperature showed a decreasing trend by a factor of -0.13 per year in the study area over study period. However, the *kiremt* maximum temperature did not show statistically significant trend at $P\leq$ 0.05 (Table 5).

The *belg* maximum temperature varied between 24.5 and 32.5 ^{O}C and *belg* average maximum temperature over the study area was 27.69 ^{O}C. The proportion of variation in *belg* maximum temperature explained by the year was 22% (Table 4). The analysis of Mann-Kendall test statistics value of Sen's Slope indicated that *belg* maximum temperature showed an increasing trend by a factor of 0.06 ^{O}C per year. However, the *belg* maximum temperature revealed statistically significant trend at $P\leq$0.05 (Table 5). If recent warming trends continue, most of Ethiopia will experience more than 1 ^{O}C increase in air temperature, with the warming tendency projected to be greatest in the south-central part of the country. This warming will intensify the impacts of droughts, and could particularly reduce the amount of productive crop land (Funk *et al.*, 2012).

Monthly maximum temperature was least for the month of July and August (20.5 ^{O}C) followed by September (21.3 ^{O}C) and May (22 ^{O}C) while highest monthly maximum temperature occurred in the month of March (34.3 ^{O}C) followed by April (33.6 ^{O}C) and February (32.9 ^{O}C) (Table 4). Monthly SD and CV of maximum temperature varied from 1.6 to 2.8 ^{O}C and 6.2 to 10.3% respectively. The proportion of variation in monthly maximum temperature explained by the course of time was varied from 1-43% (Table 4). Monthly maximum temperature from February to May showed an increasing trend, but from June to September and for it January showed a decreasing trend (Table 5). Similarly, monthly maximum temperature did not show significant trend except for January, February and June to September (Table 5). UNDP (2011) reported that temperature increase has been most rapid from July to September in Ethiopia (0.32 ^{O}C per decade).

Table 5. Mann-Kendall statistics for monthly, *belg, kiremt* and annual maximum temperature

Parameters	Years	Sen's Slope	Z value	Mk statistic (S)	*P*-value
Jan	30	-0.11	-0.34	-136	0.011
Feb	30	0.3	0.58	247	0.0001
Mar	30	0.01	0.03	13	0.83
Apr	30	0.01	0.04	23	0.789
May	30	0.01	0.09	42	0.463
Jun	30	-0.11	-0.4	-175	0.002
Jul	30	-0.12	-0.33	-43	0.011
Aug	30	-0.15	-0.42	-183	0.001
Sep	30	-0.14	-0.39	-173	0.002
Oct	30	-0.15	-0.52	-212	0.0001
Nov	30	-0.17	-0.49	-199	0.0001
Dec	30	-0.13	-0.36	-150	0.0001
Belg	30	0.06	0.26	115	0.041
Kiremt	30	-0.13	-0.41	-179	0.001
Annual	30	0.03	0.17	73	0.201

3.1.6.3. Annual, seasonal and monthly minimum temperature trend

The annual minimum temperature for the study area ranged from 8.9 to 18.8 ^{O}C and annual average minimum temperature was 12.8 ^{O}C. The proportion of variation in annual minimum temperature explained by the time was 39.6% (Table 6). The annual minimum temperature showed statistically significant negative trend by a factor of -0.2 ^{O}C per year, which contradicts an increasing trend of average annual minimum temperature reported in NMA (2007) throughout the country. This might be the case that minimum temperature is decreasing from time to time in the area as a result of temperature inversion (the situation of having warm air on top of cooler air, because the temperature profile of the atmosphere is inverted from its usual state mainly due to large difference between the observed maximum and overnight minimum temperatures) (Washington and Parkinson, 2005). Parry *et al.* (2007) argued that changes in temperature are not globally uniformly varies temporally and spatially. Similar to present study Belay *et al.* (2014) reported a decreasing trend for annual minimum temperature by -0.12 ^{O}C at Butajira station in the study period of 1975-2009.

Table 6. Descriptive statistics for *belg, kiremt* and annual minimum temperature at Indibir station (1986-2015)

Parameters	Min	Q 1 (25%)	Q2 (50%)	Q3 (75%)	Max	Mean	R^2	SD	CV (%)
Jan	5.6	8.5	11.7	13.4	21.1	11.9	0.33	3.9	33.6
Feb	6.74	9.017	11.72	13.57	19.69	12.11	0.49	3.57	29.5
Mar	8.03	10.17	11.83	13.53	20.4	12.6	0.54	3.21	25.5
Apr	9.41	11.31	12.65	14.22	22.14	13.49	0.18	3.12	23.1
May	10.21	11.67	12.31	14.24	22.08	1358	0.19	3.18	23.4
Jun	9.28	11.78	12.65	13.79	21.48	13.49	0.16	2.93	21.8
Jul	21.92	12.01	12.35	13.59	21.95	13.29	0.08	2.74	20.6
Aug	10	11.67	12.48	14.57	21.11	13.34	0.10	2.69	20.2
Sep	8.95	11.61	12.38	14.89	20.85	13.43	0.11	2.86	21.3
Oct	7.3	9.9	12.2	14.2	18.5	12.6	0.30	3.3	26.2
Nov	4.1	8.5	12.4	14.6	19.9	12.3	0.50	4.2	33.8
Dec	4.7	7.1	10.8	13.6	19.9	11.1	0.48	4.3	38.4
Belg	9.19	10.7	12.19	13.89	19.85	12.96	0.41	2.92	22.5
Kiremt	9.45	11.91	12.56	14.23	21.34	13.39	0.12	2.72	20.3
Annual	8.86	10.62	11.99	14.24	18.78	12.76	0.39	2.82	22.1

Min = minimum value, Q1 (25%) = first quartile, Q2 (50%) = second quartile, Q3 (75%) = third quartile, max = maximum value, SD ($\pm$) = standard deviation, R^2 = coefficient of determination, CV = coefficient of variation

The *kiremt* minimum temperature varied between 9.5 and 21.3 ^{O}C and *kiremt* average minimum temperature over the study area was 13.4 ^{O}C. The *kiremt* season CV and SD for minimum temperature were 20.3% and 2.7 ^{O}C respectively. The proportion of variation in *kiremt* minimum temperature explained by the year was 12% (Table 7). The *kiremt* minimum temperature decreased significantly by a factor of -0.09 ^{O}C per year (Table 7). This result contradicts USAID (2015) in which temperature increase of 1.3 ^{O}C was reported. The *belg* minimum temperature varied between 9.2 and 19.9 ^{O}C and *belg* average minimum temperature over the study area was 12.9 ^{O}C. The *belg* season CV for minimum temperature was 22.5% with SD of 2.92 ^{O}C. The proportion of variation in *belg* minimum temperature explained by the time was 41% (Table 7). *Belg* minimum temperature showed a negative trend of -0.16 ^{O}C per year, and this trend was statistically significant at $P \leq 0.05$ (Table 7).

Monthly minimum temperature was least for the month of November (4.1 ^{O}C) followed by December (4.7 ^{O}C) and January (5.6 ^{O}C) while maximum monthly minimum temperature was recorded in the month of April (22.1 ^{O}C) followed by May (22.1 ^{O}C) and July (21.9 ^{O}C) (Table 6). The proportion of variation in monthly minimum temperature explained by the time was varied from 8-54% (Table 7). The monthly minimum temperature from January to December showed a decreasing trend. There is no month that showed an increasing trend in the time series over the study period. The monthly minimum temperature *P*-values showed statistically significant trend for January-December months (Table 7). The finding is in conformity with NMSA (1996) that reported the lowest minimum temperature during October to December months. As a result, extreme minimum of night and early morning temperatures in the month of November, December and January favors occurrence of frost action in the study area.

Table 7. Mann-Kendall Statistics for monthly, *belg, kiremt* and annual minimum temperature

Parameters	Years	Sen's Slope	Z value	Mk statistic (S)	*P*-value
Jan	30	-0.30	-0.41	-168	0.001
Feb	30	-0.28	-0.52	-225	0.0001
Mar	30	-0.24	-0.59	-259	0.0001
Apr	30	-0.14	-0.43	-185	0.001
May	30	-0.11	-0.44	-191	0.0001
Jun	30	-0.11	-0.32	-141	0.012
Jul	30	-0.08	-0.29	-125	0.026
Aug	30	-0.08	-0.26	-115	0.041
Sep	30	-0.11	-0.31	-135	0.016
Oct	30	-0.26	-0.47	-190	0.0001
Nov	30	-0.39	-0.57	-230	0.0001
Dec	30	-038	-0.52	-209	0.0001
Belg	30	-0.16	-0.57	-247	0.0001
Kiremt	30	-0.09	-0.33	-143	0.011
Annual	30	-0.20	-0.53	-229	0.0001

3.1.7. Rainfall anomaly

3.1.7.1. Annual rainfall anomaly

Year-to-year variation of annual rainfall is presented in terms of normalized rainfall anomaly index as shown in Figure 5. The study area experienced both wet and dry years over the study period. Of the observed 30 years, 17 years (56.7%) recorded rainfall above long term average, but 13 years (43.3%) recorded below the long term average annual rainfall. The largest negative deviation was occurred during the year 1992 and the highest positive anomalies was registered during year 2010. These findings were in conformity with study carried out by Kidane *et al*. (2010) about years of drought and floods in Ethiopia.

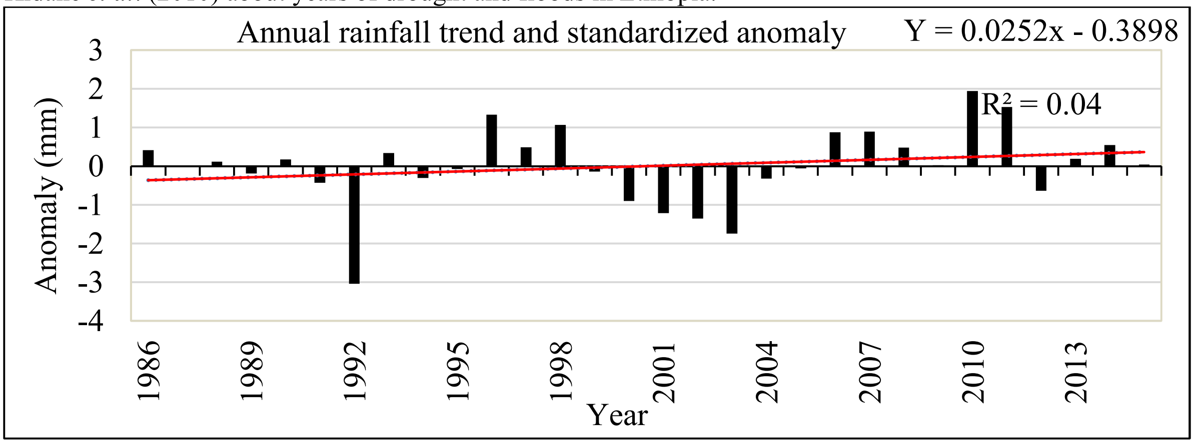

Figure 1. Annual rainfall trend and standardized anomaly at Indibir station (1986-2015)

3.1.7.2. Kiremt rainfall anomaly

The *kiremt* rainfall anomaly series had two distinct periods i.e. rainfall anomalies below normal and above normal (Figure 6). Thirteen years (43.3%) of the study period experienced strong negative departure from the mean *kiremt* rainfall. The persistence of negative anomalies for these years indicated that the study area has been experiencing dry conditions. Seventeen years (56.7%) of the study period were years of wet period with strong positive departure from the mean *kiremt* rainfall. The positive rainfall anomalies during this year indicated that the study area experienced wet conditions (Figure 6). The dry years clearly demonstrated that rain-fed crop production in the area have been challenged by risk of low rainfall over the study period. This is study result is in agreement with Viste *et al*. (2012) reported that 2002 and 2009 years were found *kiremt* drought years over Ethiopia.

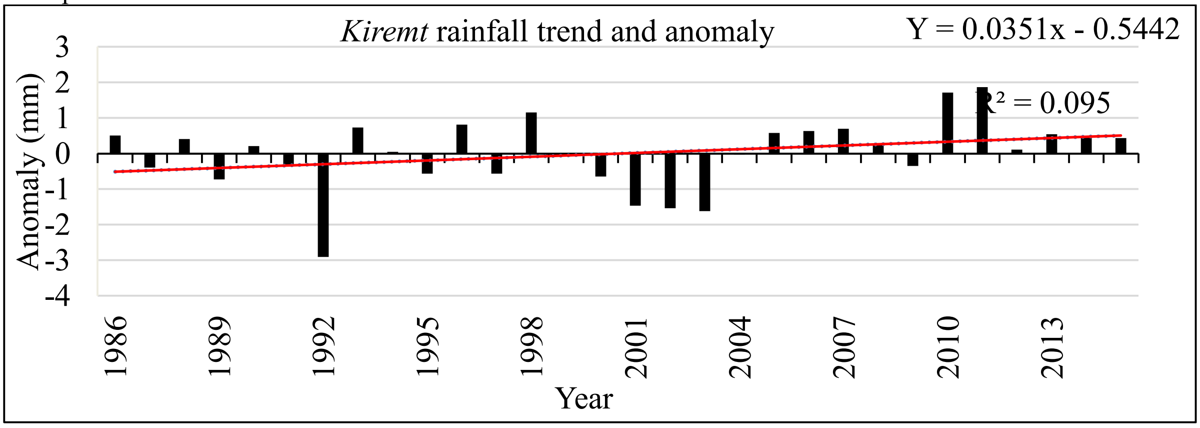

Figure 2. *Kiremt* rainfall trend and standardized anomaly at Indibir station (1986-2015)

3.1.7.3. Belg rainfall anomaly

With regard to the *belg* season fifteen years (50%) of the study period experienced strong to weak negative departure from the mean rainfall. The persistence of negative anomalies for these years indicated that the study area had known dry conditions. In contrast 15 years (50%) of the study period had wet period with strong and weak positive departure from the mean of the *belg* rainfall (Figure 7). The positive rainfall anomalies during this year indicated that Abshege had experienced wet conditions. North eastern Ethiopia was experienced to drought in the years of 1992, 1997, 2000, 2002, 2009 and 2011 (Viste *et al*., 2012).

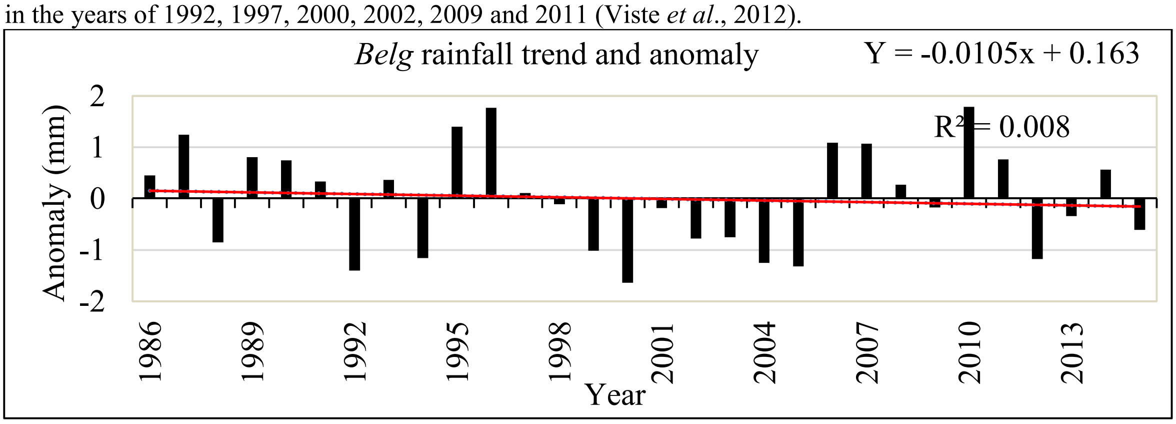

Figure 3. *Belg* rainfall trend and standardized anomaly at Indibir station (1986-2015)

4. Conclusion

Indibir weather station has respective annual, *belg* and *kiremt* mean rainfall of 1182.2, 282.26 and 796.43 mm. The annual and seasonal rainfall totals showed that the area has moderate to high variable rainfall condition. Observed trends also indicated decreasing in *belg* rainfall and an increasing in annual and *kiremt* rainfall totals, but trend were non-significant.

The study area has a mean annual, *belg* and *kiremt* maximum temperature of 27.03, 27.7 and 24.1 ^{O}C and also has a mean annual, *belg* and *kiremt* minimum temperature of 12.8, 12.9 and 13.4 ^{O}C, respectively. Annual and *belg* maximum temperature showed an increasing trend, but *kiremt* maximum temperature revealed a decreasing trend. However, the temporal variability of maximum temperature is less as compared to minimum temperature. The changes in maximum temperature during *belg* and *kiremt* season were statistically significant, but not in the annual basis. Significant decreasing trends were also found in annual, *belg* and *kiremt* minimum temperatures.

The annual rainfall in the region is characterized by fluctuation of wet and dry years in a periodic pattern. Total of the 30 years of observation, 17 years (56.7%) recorded above the long term average annual rainfall, but 13 years (43.3%) recorded below long term average annual rainfall amount. The standardized anomalies of *kiremt* rainfall revealed 13 years (43.3%) with strong negative departure from the mean of *kiremt* rainfall. Seventeenth years (56.7%) were years of wet period with weak to strong positive departure from the mean *kiremt* rainfall. The SAI of the *belg* rainfall revealed 15 years (50%) had strong to weak negative departure from the mean of *belg* rainfall. In contrast, fifteenth years (50%) were years of wet period with strong and weak positive departure from the mean of the *belg* rainfall. Development planners of the area should design strategies and plans by taking into account a declining *belg* rainfall and increasing temperature impacts on livelihood of local communities. Increase in *kiremt* total rainfall will result in a decrease in agricultural production in the area, therefore emphasis should be given to manage and drained water in the field during high rainfall and flooded condition.

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