Journal of Climatology & Weather Forecasting
ISSN: 2332-2594
OPEN ACCESS Freely available online
Research Article

Observed Climate Variability, Trends and Extremes in South-Eastern Highlands of Ethiopia

Abu Tolcha Gari*, **Almaz Nigussie Chukala**

Ethiopian Institute of Agricultural Research, Kulumsa Research Center, Ethiopia

ABSTRACT

Ethiopia is a country of natural contrasts in the greater horn of Africa. Ethiopia has hitherto been prone to extreme weather events, with very high intensity and spatially and temporally explicit variability. Therefore, the objective of this paper is to analyze the variability and trends of rainfall onset, cessation, Length of Growing Season (LGS), annual and seasonal rainfall and climate indices.

The user-defined method was applied to determine the onset date, cessation date, and LGS in this analysis. The non-parametric Mann-Kendall trend test was used for trend analysis in onset date, cessation date, LGS, annual and seasonal rainfall, and climate indices.

The onset of the rainy season was highly variable at Asasa and Kulumsa with the CV value of 30% at both stations. The lowest variability is observed at Dinsho and Ginir with a CV value of 10%. On the other hand, the season ceased early on 11th September at Asasa and late end on 16th November at Ginir. The lowest variability of cessation date was determined at Arsi Robe with a coefficient of variation value of 1% and the highest variability at Dinsho with a 10% CV value during the study period. Overall, the onset of the rainy season was highly variable than the end of the season in the study area. The trend analysis of weather events showed that the onset of the rainy season was insignificantly increased in all stations except Dinsho and Ginir whereas the cessation date and LGS were decreased overall sites except Ginir and Kulumsa. This indicated that late-onset and early-cessation of the rainy season were experienced in the study area. The trend analysis of climate indices indicated that most of the temperature indices were changed significantly while most of the precipitation indicators showed non-significant and decreasing trends.

Keywords: Climate index; Climate variability; Onset and cessation date; Rainfall anomaly

INTRODUCTION

Ethiopia is a country of natural contrasts in the greater horn of Africa. Ethiopia's varied topography has traditionally been associated with three mega climatic zones. These traditional agro-climatic zones are known as Kolla (warm semiarid), less than 1500 m above sea level; Woinadega (cool sub-humid temperate zone), 1500 m-2400 m above sea level; and Dega (cool and humid zone), mostly greater than 2400 m above sea level. As the population increased and agricultural activities expanded, two more zones were added at the extreme ends of the agro-climatic spectrum. These are Bereha (hot arid) and Wurch (cold and moist). Geographically also, Ethiopia can be subdivided into five mega agro-ecological zones based on moisture and land use: 1) drought-prone highlands with insufficient rainfall; 2) rainfalls sufficient highlands dominated by enset-based farming; 3) rainfall-sufficient areas mainly planted to cereal-based crops; 4) generally dry, pastoral lowland areas and 5) humid lowland areas further inland that primarily support crop farming.

According to both classifications noted above, agricultural areas have spatially explicit potential and/or degree of vulnerability. The Dega (cool and humid zone) with sufficient rainfall for instance, are of high potential productivity or less vulnerable, while Kolla and dry pastoral areas are generally of low potential or highly vulnerable to climate risks. Therefore, specific geographic locations and topography provide a unique potential and/or vulnerability of Ethiopian agriculture to climate risks.

Ethiopia has hitherto been prone to extreme weather events, where rainfall is highly erratic, and most rain falls in convective storms, with

Correspondence to: Abu Tolcha Gari, Ethiopian Institute of Agricultural Research, Kulumsa Research Center, Ethiopia, Telephone: +251912812790; E-mail: tolchabu@gmail.com

Received: September 28, 2020; **Accepted:** October 15, 2020; **Published:** October 25, 2020

Citation: Gari AT, Chukala AN (2020) Observed Climate Variability, Trends and Extremes in South-Eastern Highlands of Ethiopia. J Climatol Weather Forecast 8:265.

very high intensity and spatially and temporally explicit variability. Variations in the mean state and other climate statistics (standard deviation, the occurrence of extremes like drought and floods, etc.) beyond those of individual weather events on all temporal and spatial scales are referred to as climate variability. Variability may be internal (result from natural or internal processes within the climate system) or external (result from variations in natural or anthropogenic external forces). In a normally distributed parameter, variability occurs when changes in the mean, the variance, or both cause the probability distribution to 'shift" resulting in changes in the frequency of occurrence of extreme events.

Risks associated with climate variability are the hottest topic, with this variability known to occur between a given bounded ranges of values around the average. The enhanced frequency in droughts both temporally and spatially over the past decades is making a complex challenge in ensuring food sovereignty of Ethiopia [1]. Accordingly, Ethiopian agriculture is inevitably linked to three of the greatest challenges of the 21st century i.e.; achieving food security in the face of the risks associated with climate variability, adapting to and mitigating climate change.

Therefore, evidence is clear and growing that Ethiopia needs to develop more effective responsive strategies to manage climate induced risks in agriculture. Also, the substantial advances in climate science have generated a great deal of interest in the potential contribution of climate information in improving smallholder productive capacity and risk management [2,3].

Therefore, this study was aimed at analyzing the observed climate variability and trends in Arsi, west Arsi and Bale Zones that represents mid to highland agro-ecologies and mainly growing areas of cereals, highland pulses and horticultural crops.

MATERIALS AND METHODS

Description of study area

The study was conducted in selected sites of Arsi, West Arsi and Bale Zones representing different agro ecologies (lowland, medium highland and highland) areas which are the outskirts of Kulumsa Research Center. The weather data used in these analyses was obtained from the National Meteorology Agency (NMA) and Ethiopian Institute of Agricultural Research (EIAR). The location map of study area and distribution of weather stations used in this study is depicted in Figure 1.

The rainfall regime over the area is typically bimodal, with the main rains, known as the Kiremt (JJAS), occurring from June through to September, and the short rains, known as the Belg (FMAM), occurring during February to May. More than 85% of the rain is occurring in Kiremt season from June to September, with July and August being with wettest months, most of time high rainfall amount recorded in August month. The Belg rains are not sufficiently reliable to permit crop planting each year, and when they do occur, they can merge into the Meher. The mean annual rainfall in the area ranges from 500 mm to 2000 mm, depending on altitude, but in spite of this, and because of excessive runoff, water shortage is a common problem for 5 or 6 months per year in many parts of the highlands. The annual mean maximum and minimum temperature are ranges from 5.7°C-14°C and 18°C -27.8°C, respectively.

The soils of the study area in general, are dominated by Alfisols, Vertisols and inceptisols. They are red to light red-brown on the mountains and hillsides, red-brown on the intermediate slopes, brown to dark brown on the undulating plains, and black in the lower parts and bottomlands. The red-brown to dark brown soils are the most suitable for agriculture, particularly for grain crops. The major soil related problems are erosion on the slopes, poor drainage on the bottomlands and generally low levels of available phosphorus and nitrogen.

Data and quality control

The percentage of missing values was checked for each station and stations with missed values less than 10% out of the total data series were considered in this analysis. The procedure in excel-based RclimDex 1.0 software was used to identify data quality problems such as keying errors, invalid values of rainfall and temperatures and outliers. Accordingly, daily rainfall amounts less than 0 (if any) are removed, and both daily maximum and minimum temperatures are set to a missing value, or if daily maximum temperature is less than the respective daily minimum temperature. Decision System Support for Agro-technology Transfer (DSSAT) software was used to fill the missing data values.

Analytical methods

Onset, cessation and Length of Growing Season (LGS): The user defined method of Stern was applied to determine onset date, cessation date and LGS in this analysis [4]. Accordingly, a day with accumulated rainfall amount of 20 mm in three consecutive days with no consecutive dry spells greater than 10 days within 30 days from planting is defined as the onset date. The cessation of the rainy season is defined as, any day when the soil water reaches zero with the assumption of a fixed average evapotranspiration of 5 mm per day and 80 mm/meter of soil water holding capacity to be searched after first of September [4]. The Length of the Growing Period (LGS) is determined by taking the difference between the onset and the cessation.

Trend analysis

Mann-Kendall was used for trend test in these analyses. It is one of the most widely used non-parametric tests for detecting a trend in climatic time series and preferred for trend analysis when more than one stations are tested in a single study [5]. Also, this non-parametric test is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or non-linear [6,7]. MK test compares the relative magnitude of a data value with all subsequent data values in the ordered time series. The presence of a statistically significant trend was evaluated using the Z value. A positive value of Z indicates an upward and negative value of Z indicates downward trend.

Analysis of climate indices

A core set of 27 indices has been developed by the Expert Team on Climate Change Detection and Indices (ETCCDI) to standardize the definitions and analysis of extremes. Climate indices are used to monitor climate change as and when is happens based on daily temperature and precipitation as data input. The climate index is the mean of several climate change indicators [8]. The advantage of using Indices for climate change detection is that 1) they can be applied to different climate parameters such as TX, TN, RR; 2) they enable an easy comparison of trends between different climate regions; and 3) they are easily understandable and manageable for impact studies.

All 27 core indices of which 16 are temperature related and 11 are precipitation related have been computed using RClimDex software. A boot strapping method proposed by Zhang was implemented in RClimDex and used to compute indices analyzed in this study [9]. The bootstrap procedure removes the inhomogeneity and thus eliminates possible bias in the trend estimation of the relevant indices.

RESULTS AND DISCUSSION

Onset, cessation and Length of Growing Season (LGS)

The analysis of long term (1981-2017) rainfall data revealed that the onset of rainy season was highly variable at Asasa and Kulumsa with the CV value of 30% at both stations. The lowest variability is observed at Dinsho and Ginir with the CV value of a 10%. The mean of onset date indicates that Arsi Robe has the earliest onset during the 1st decade of April whereas the latest onset is recorded at Ginir during the last decade of August. Moreover, the onset date was determined to be on/before 16th March (75 DOY) and 24th August (237 DOY) in one out of four years (25%) and on/before 15th April (105 DOY) and 21st September in three out of four years (75%) at Arsi Robe and Ginir stations, respectively, while it lays between these values for the remaining stations (Figure 2 and Table 1).

On the other hand, the season ceased early on 11th September (254 DOY) at Asasa and late end on 16th November (320 DOY) at Ginir. Furthermore, the season ceased in one out of four years on/before 2nd September (245 DOY) and 2nd November (306 DOY), and on/before 15th September (258 DOY) and 26th November (330 DOY) in three out of four years at Asasa and Ginir stations, respectively (Table 1). The lowest variability of cessation date was determined at Arsi Robe with coefficient of variation value of 1% and highest variability at Dinsho with a 10% CV value during the study period (Table 1). Overall, the onset of rainy season was highly variable than the end of the season in the study area which is in lined with the previous work over Ethiopia [10]. The mean Length of Growing Season (LGS) was ranged from 72 to 199 days across the study sites having the highest variability at Sinana (CV=40%) and lowest variability at Arsi Robe and Bekoji (CV=12%) during the study period.

The trend analysis of weather events showed that the onset of rainy season was insignificantly increased in all stations except Dinsho and Ginir whereas the cessation date and LGS were decreased over all sites except Ginir and Kulumsa during study period. The trend was significant at Asasa and nearly significant at Ginir for cessation date and significant at Kofele and nearly significant at Asasa for length of growing season. This indicated that late onset and early cessation of the rainy season was experienced in the study area and this could reduce the length of growing season which in turn affects the crop production over the area.

Variability and trends of annual and seasonal rainfalls

Table 2 shows the trends and descriptive statistics of annual and

Table 1: Descriptive statistics and trends of weather events.

Parameters	Asasa	Arsi Robe	Bale Robe	Bekoji	Dhera	Dinsho	Ginir	Kofale	Kulumsa	Sinana
Descriptive statistics for onset										
Mean	133.1	91.3	181.3	96.2	172.2	169.5	242.9	88.6	114.3	218.6
SD	39.9	19.89	19.3	19.9	23.9	17.1	23.8	17.2	34.5	23.5
0.25	95	75	165	79	180	154	237	76	84	203
0.75	173	105	196	108	187	180	264	93	130	236
CV	0.3	0.19	0.11	0.21	0.14	0.1	0.1	0.19	0.3	0.11
MK Z	1.2	0.99	0.37	0.89	0.14	-0.77	-0.01	0.92	0.31	0.3
Slope	0.53	0	0.12	0.2	0	-0.06	0	0.14	0.15	0.1
Descriptive statistics for cessation										
Mean	254.2	259.8	273.6	276.2	269.3	299.6	320.6	288.5	268.4	293.7
SD	10.1	1.55	15.8	17.9	16.6	29.9	16.4	25.5	12.6	16.4
0.25	245	259	261	264	263	274	306	270	259	280
0.75	258	260	282	283	276	319	330	310	271	302
CV	0.04	0.01	0.06	0.06	0.06	0.1	0.05	0.09	0.05	0.06
MK Z	-2.16^{*}	-1.15	-0.85	-0.21	-1.27	-1.41	1.85^{+}	-1.23	0.54	-1
Slope	-0.24	-0.458	-0.1	-0.07	0	-0.63	0.46	-0.6	0	-0.25
Descriptive statistics for LGS										
Mean	121.1	168.5	92.3	180	97.1	130.1	72.7	199.9	154.1	75.1
SD	39.7	19.67	21.8	21.2	29.5	34.7	28.6	30.4	38.1	30.2
0.25	83	154	80	167	90	106	54	180	132	48
0.75	158	184	108	195	121	152	80	228	184	99
CV	0.33	0.12	0.24	0.12	0.3	0.27	0.39	0.15	0.25	0.4
MK Z	-1.70^{+}	-1.6	-0.35	-0.75	-1.19	-0.69	1.27	-1.96^{*}	0.39	-0.77
Slope	-1.06	-1	-0.15	-0.33	-0.51	-0.34	0.42	-1.07	0.15	-0.33

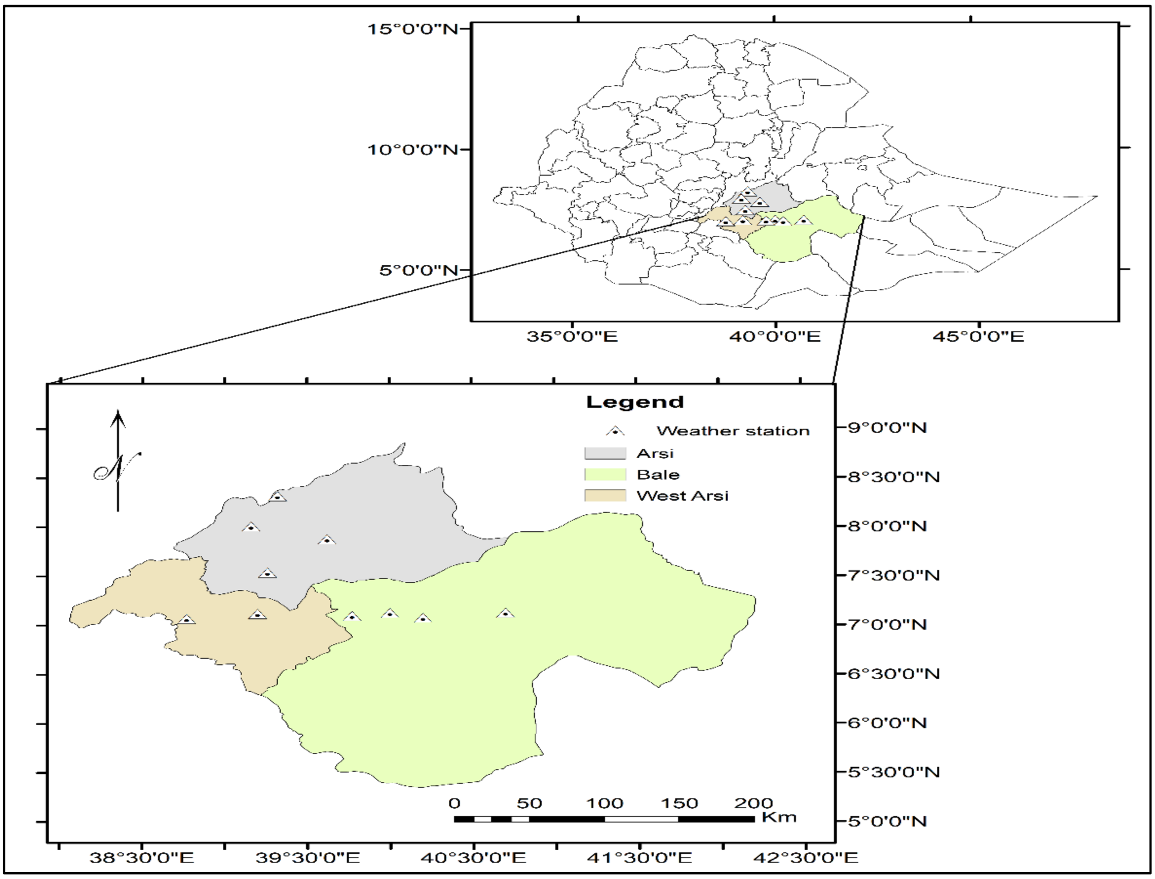

Figure 1: Location map of the study area .

seasonal rainfall totals of the study sites during study period (1981-2017). The mean annual total rainfall showed that the lowest and highest annual rainfall totals across the study sites during the study period were 639.4 mm and 1346.7 mm received at Asasa and Dinsho, respectively, (Table 2). The minimum and maximum annual rainfall totals received by the study areas during the period ranges from 359.1 mm to 1052.5 mm and 801.0 mm to 2358.9 mm at Asasa and Dinsho respectively, while lays between these values for the remaining stations [11]. The Belg (FMAM) seasonal rainfall totals were highly variable as compared to Kiremt (JJAS) and annual rainfall totals in most of the study sites. Moreover, the Coefficient of Variation (CV) value of the Belg rainfall is very high as compared to that of annual and Kiremt rainfall totals which show the high variability of Belg rainfall than annual and Kiremt rainfall totals in the study area (Table 2).

Beside to this the trend analysis revealed that seasonal and annual rainfall totals were significantly decreased in most of the stations. The annual rainfall total was highly and significantly decreased at Arsi Robe and Kofele whereas insignificantly increased at Bale Robe, Ginir and Kulumsa areas (Table 2). Kiremt and Belg seasonal rainfall totals were highly and significantly decreased at Kofele and Bekoji stations, respectively (Figure 3 and Table 2).

Standardized annual and seasonal rainfall anomalies

The standardized annual and seasonal rainfall anomaly of the study sites over study period is depicted in Figures 4-6. Annual and seasonal rainfalls are highly variable in all the study sites over the study period as indicated in the Figure 4. It could be clearly observed from the figures that the seasonal and annual rainfall anomaly was below the mean in most of the years during the study period in the study sites. Based on the Standardized Precipitation Index (SPI) classification moderately wet (1 to +1.49), severely wet (1.5 to +1.99) and extremely wet (+2 and above) as well as moderately dry (-1 to -1.49) and severely dry (-1.5 to -1.99) periods were identified for both annual and seasonal rainfalls in most of the study sites. Moreover, there were some extremely dry (-2 and below) years at Kulumsa, Kofele and Sinana stations during the study period (1981-2017). For instance, the year 2009 at Kofele, 1991 at Kulumsa and 2000 and 2010 at Sinana were extremely dry as showed by the Belg (FMAM), annual and Kiremt (JJAS) rainfall anomalies, respectively (Figure 6).

On the other way Kiremt rainfall anomaly showed that 1984 at Arsi Robe, 1994 at Asasa, 2014 at Bekoji, 1988 and 2017 at Bale Robe, 1988-1990 at Dinsho, 2012 at Ginir, 1984 and 1988 at Kofele, 2017 at Kulumsa and 1999 at Sinana were extremely wet years (Figures 4-6). Conversely, 1988 at Arsi Robe, 1983 at Asasa and Bekoji, 1987 and 2010 at Bale Robe and Kulumsa, 1989 and 1994 at Dinsho, 2010 at Ginir and Sinana were extremely dry years during Belg season (Figures 4-6).

In general, there were below and above the mean seasonal and annual rainfall anomalies during the study period over the study area with high frequency of dry periods. This implies that, there was high variability in both seasonal and annual rainfall totals which in turn could affect crop production and productivity in the study area.

Trends of extreme climate indices/Trends of temperature indices

Annual trends for the extreme temperature indices during 1981-2017 are presented in Table 3. The trend analysis revealed that most

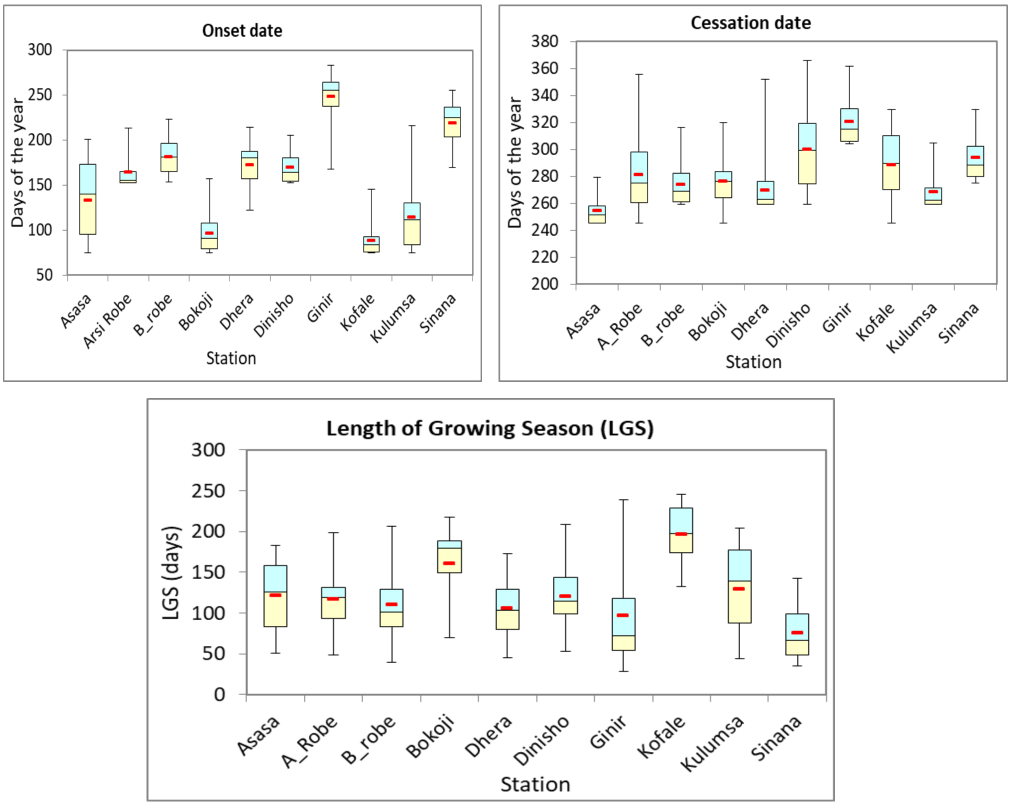

Figure 2: Box and whisker plots of onset date, cessation date and LGS.

Table 2: Descriptive statistics and trends of annual and seasonal rainfall totals.

Parameter	Arsi Robe	Asasa	Bale Robe	Bekoji	Dhera	Dinisho	Ginir	Kofale	Kulumsa	Sinana
Descriptive statistics and trends of annual rainfall										
Mean	1001.4	639.4	844.5	1049.7	673.9	1346.7	1006.0	1232.1	839.2	882.8
SD	232.6	140.4	126.1	152.0	150.0	389.9	240.3	204.6	120.5	155.4
Minimum	573.9	359.1	592.4	765.3	371.2	801.0	659.9	846.9	592.4	609.9
Maximum	1612.5	1052.5	1149.3	1368.7	1111.9	2358.9	1453.4	1809.9	1163.6	1372.0
CV	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.2	0.1	0.2
MKZ	-2.47*	-2.84**	1.40	-2.34*	-0.82	-1.84+	0.25	-3.68***	1.06	-0.95
Slope	-9.32	-4.85	3.13	-5.53	-1.96	-9.40	1.26	-10.08	2.30	-2.33
Descriptive statistics and trends of JJAS rainfall										
Mean	413.9	404.5	400.0	593.7	439.9	628.2	208.8	573.7	401.0	330.0
SD	173.8	85.3	79.8	115.1	103.3	197.0	84.5	109.4	82.2	68.7
Minimum	181.7	297.5	256.2	354.1	234.1	294.0	71.2	427.1	256.2	178.4
Maximum	1070.6	634.6	588.3	837.2	725.0	1097.3	553.4	820.6	619.6	495.2
CV	0.4	0.2	0.2	0.2	0.2	0.3	0.4	0.2	0.2	0.2
MKZ	0.64	-2.00*	2.15*	0.35	-0.38	-1.63	-0.04	-3.07**	2.20*	-0.67
Slope	1.72	-2.66	2.42	0.81	-0.62	-4.04	-0.02	-4.62	2.49	-0.62
Descriptive statistics and trends of FMAM rainfall										
Mean	401.3	161.0	294.4	336.6	166.9	445.1	497.5	458.7	289.1	368.6
SD	118.5	79.6	90.6	131.1	91.5	175.2	198.1	104.8	86.1	124.2
Minimum	142.1	42.0	189.1	104.9	6.4	153.5	220.0	215.0	189.1	100.5
Maximum	698.6	326.0	569.1	616.3	405.6	874.7	1010.6	630.6	569.1	792.2
CV	0.3	0.5	0.3	0.4	0.5	0.4	0.4	0.2	0.3	0.3
MKZ	-2.45*	-2.21*	0.09	-2.54*	-1.95+	-1.50	-1.43	-2.39*	-0.25	-0.67
Slope	-4.72	-2.97	0.15	-5.41	-2.63	-4.32	-4.30	-4.07	-0.15	-1.16

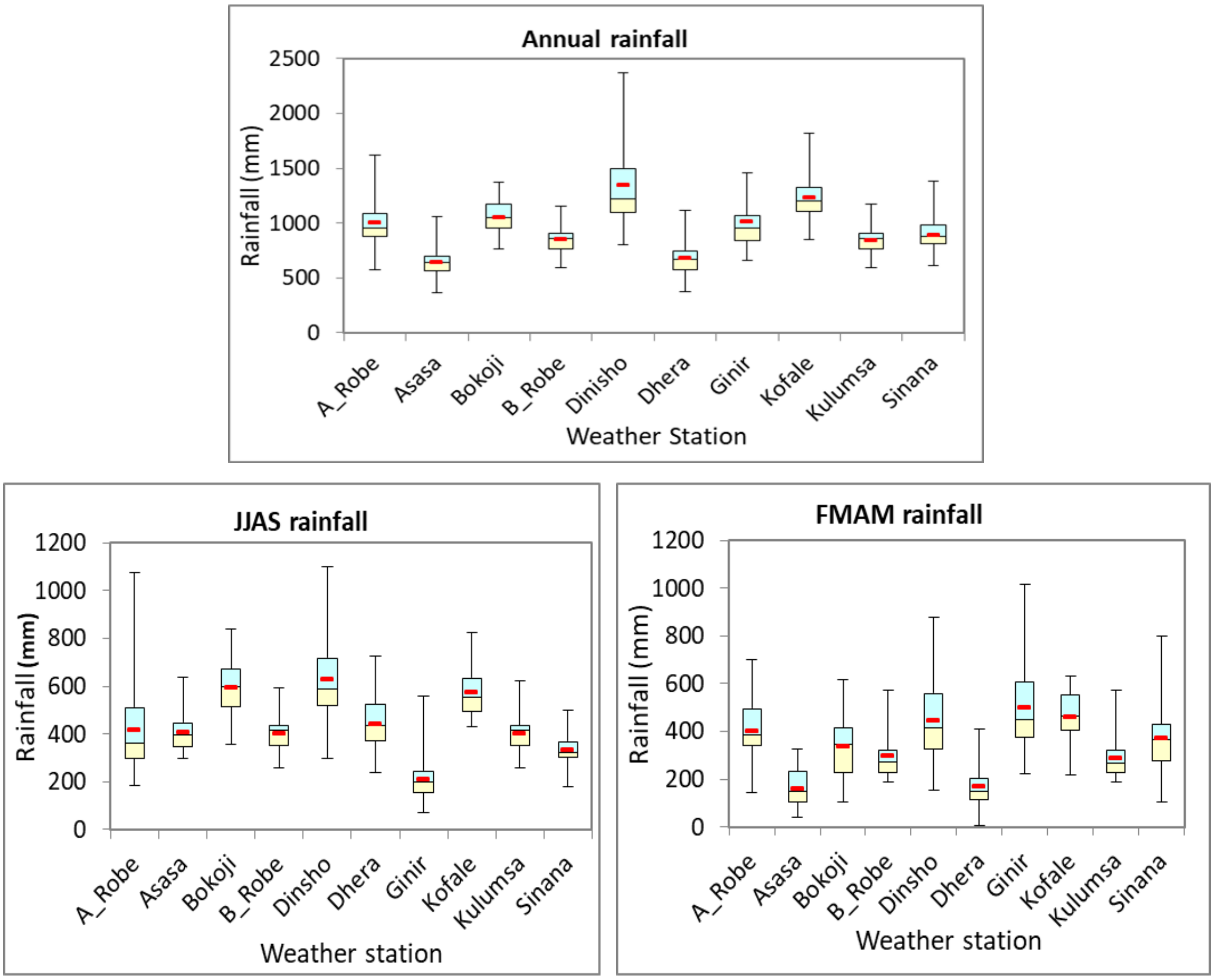

Figure 3: Box and whisker plots of annual and seasonal rainfall.

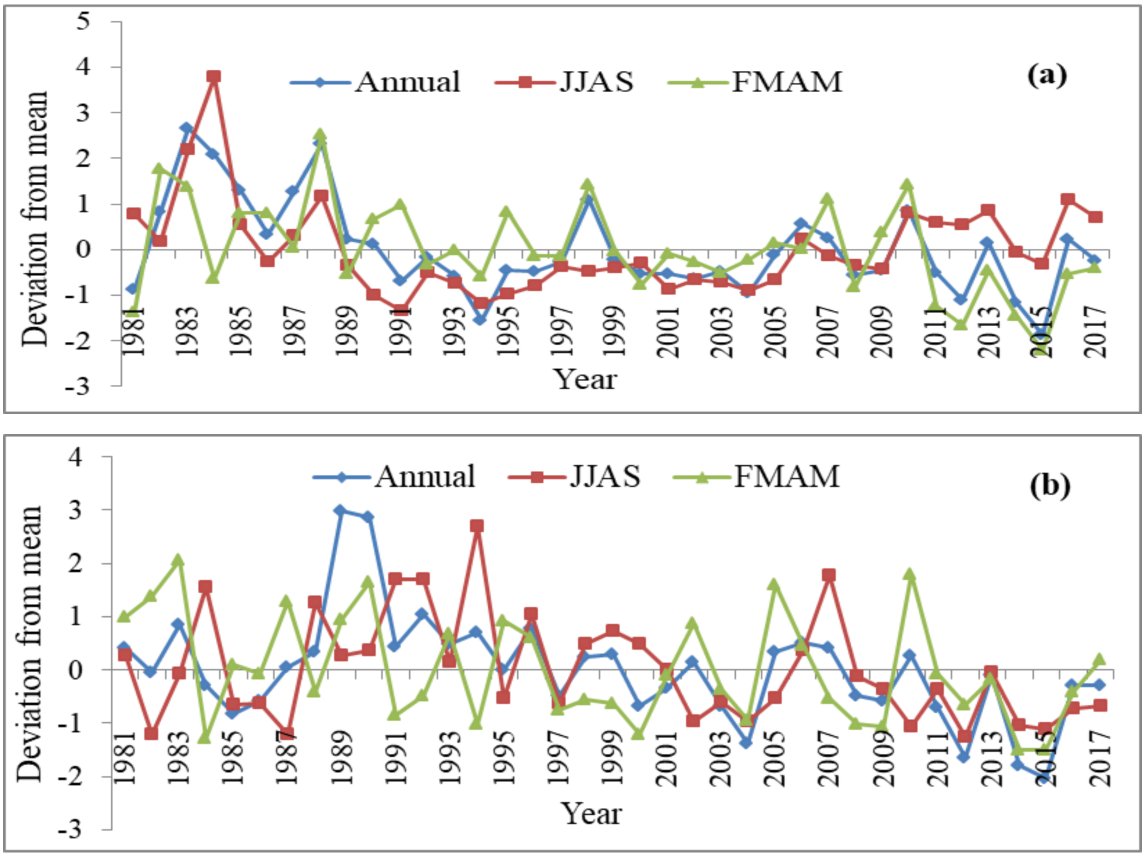

Figure 4: Standardized annual and seasonal rainfall anomalies at a): Arsi Robe and b): Asasa.

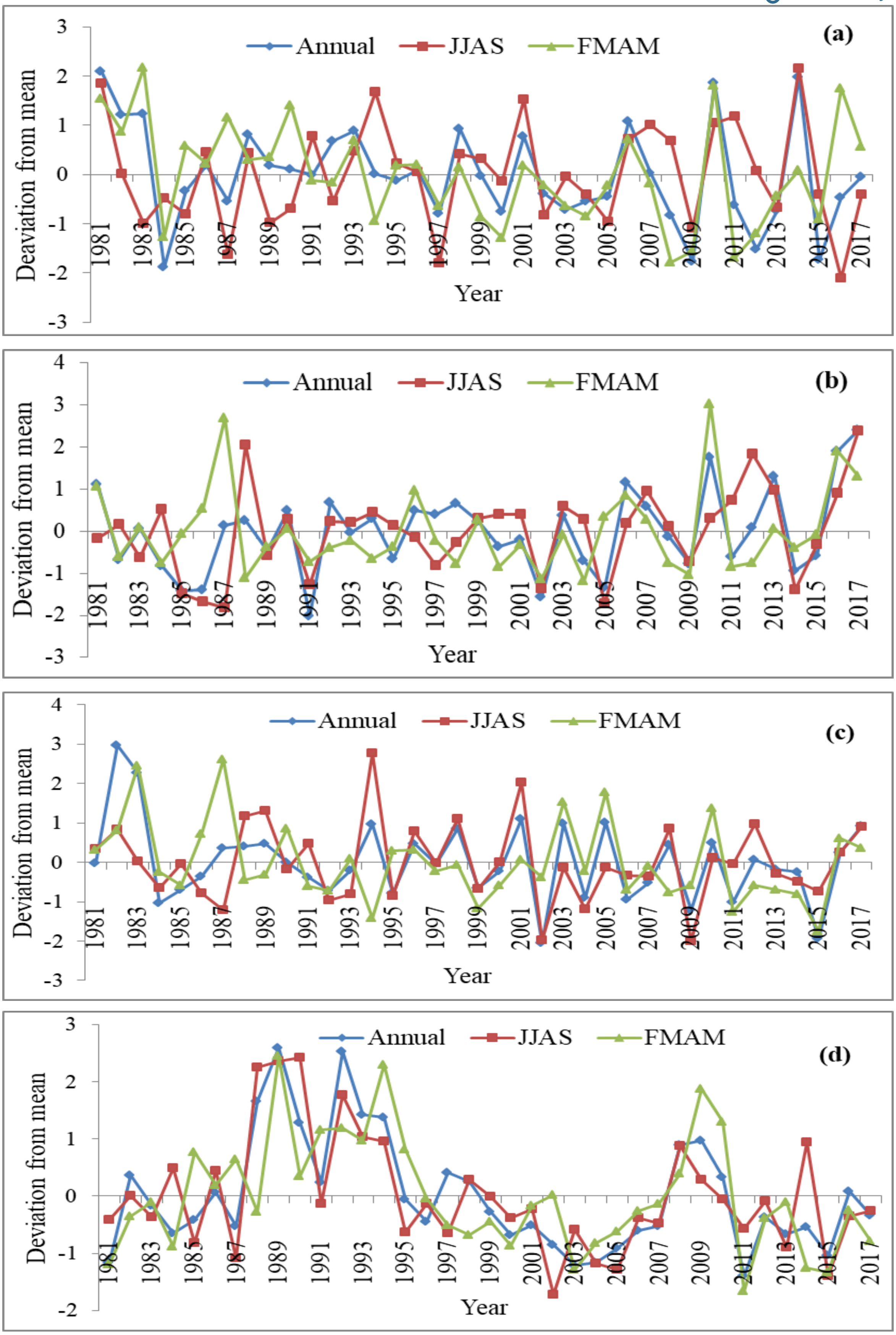

Figure 5: Standardized annual and seasonal rainfall anomalies at a): Bekoji; b): Bale Robe; c): Dera; d): Dinsho.

of the temperature indices were changed significantly over most of the study sites and there is a spatial coherence across the sites (Table 3). The annual trends of all indices are tested for statistical significance at the 95% and 99% confidence level for each study site. As it could be observed from Table 3, the number of summer days (SU25), averages of warm night frequency (TN90), warm day frequency (TX90), warmest night temperature (TNx), maximum value of daily maximum temperature (TXx) and maximum value of daily minimum temperature (TNx) display the warming trends in most of the study sites. Among the threshold indicators, the number of days with maximum temperature greater than 25°C (SU25) was strongly and significantly increased in 2.153, 1.108 days/year and decreased in 4.042 days/year at Ginir, Arsi Robe and Asasa areas, respectively, (Table 3 and Figure 7).

Among the percentile indicators, the number of warm days exceeding the 90th percentile (TX>90th p) threshold was highly and significantly increased at Arsi Robe, Bale Robe, Bekoji and Kulumsa areas. Similarly, the number of warm nights exceeding 90th percentile (TN>90th p) was highly increased over all study sites except Dhera while the trend was significant at Arsi Robe, Bekoji and Ginir areas (Figure 7). The warm spell duration (annual count of days with at least 6 consecutive days when TX>90th percentile) showed increasing trends for all sites except Asasa and Dinsho with significant trends at Bale Robe, Bekoji and Kulumsa (Table 3 and Figure 7). There was an increasing and significant trend in daily maximum value of minimum temperature (TNx) at Arsi Robe, Asasa, Bekoji and Ginir, and decreasing and significant trend at Kofele area (Table 3 and Figure 7). On the other hand, the

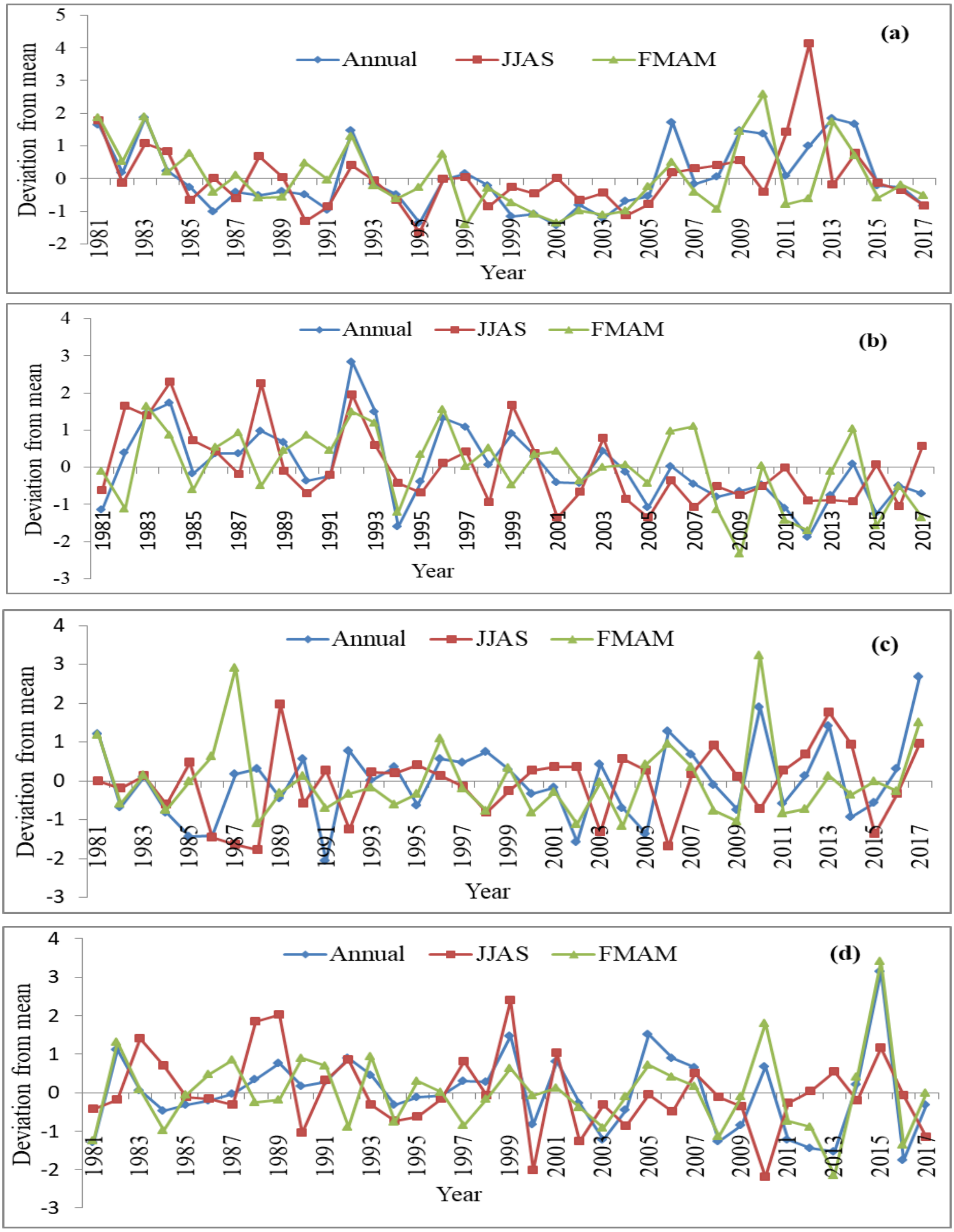

Figure 6: Standardized annual and seasonal rainfall anomalies at a): Ginir; b): Kofele; c): Kulumsa; d): Sinana.

minimum value of daily minimum temperature (TNn) showed a decreasing trend over most of the study sites.

Overall, the result indicated that, warm extremes are increasing while cold extremes decreasing in most of the study sites. This clearly shows that there has been a warming trend over study area during the study period (1981-2017). The temporal trends and spatial distribution of temperature indices is depicted in Figure 7.

Trends of precipitation indices

Unlike the temperature indicators, most of precipitation indicators showed decreasing trends in the study area during the study period (Table 4). The two annual total precipitation extremes when rainfall >95th and 99th percentile showed decreasing trends at Arsi Robe, Asasa, Bekoji, Dhera, Dinsho and Kofele areas while the trend was statistically significant at Arsi Robe, Asasa and Bekoji stations for the 95th percentile. Moreover, both have showed increasing and significant trends at Bale Robe and Kofele stations. The annual wet day total precipitation was highly and significantly decreased at Arsi Robe, Asasa and Kofele while insignificantly decreased over the remaining sites except Bale Robe and Kulumsa (Table 4 and Figure 8). Moreover, the maximum number of consecutive days with less than 1 mm rainfall (CDD) and number of wet days with <1 mm rainfall was insignificantly increased over most of the study sites. The simple daily precipitation intensity index (SDII) indicated strongly significant decreasing trends at Asasa, Dhera and Kofele sites (Table 4). Similarly, the annual total precipitation showed strongly significant trend over Arsi Robe, Asasa and Kofele stations during the study period (1981-2017).

Among the threshold indicators, a number of heavy rainfall days with daily precipitation >25 mm has been increased in all stations while the trend was statistically significant at Arsi Robe, Bale Robe and Kulumsa (Table 4 and Figure 8). Conversely, the numbers of days with daily rainfall greater than 10 mm and 20 mm have showed decreasing trends in six out of ten stations with significant trends at Arsi Robe, Asasa and Kofele stations (Table 4). Generally, most of precipitation indices are indicated decreasing trends over most of the study sites except Bale Robe, Ginir, Kulumsa and Sinana while the trend is significant at some stations.

Overall, the changes in temperature and precipitation indices indicate that there has been a change in climate over study area during the study period.

CONCLUSION

In this paper, the temporal and spatial variability and trends of weather events (onset and cessation dates of rainy season, LGS), seasonal, and annual rainfall totals and climate indices are examined for the observed climate. The study found that the onset date of rainy season was highly variable as compared to the cessation date in the study area. The trend analysis of these weather events showed that the onset of rainy season was insignificantly increased whereas the cessation date and LGS were decreased over most of the stations during the study period. This indicated that late onset and early cessation of the rainy season was experienced in the study area and this could affect the crop production by reducing the length of growing season over the area. The decreasing trends of seasonal and annual rainfall totals and high variability of seasonal rainfall than annual rainfall total is also determined in this study.

The trend analysis of temperature indices revealed that most of the indices were changed significantly over most of the study sites and there is a spatial coherence across the sites. For instance, the number of summer days (SU25), averages of warm night frequency (TN90), warm day frequency (TX90), warmest night temperature (TNx), maximum value of daily maximum temperature (TXx) and maximum value of daily minimum temperature (TNx) display the warming trends in most of the study sites. Overall, the result in-

Table 3: Annual trends of temperature indices.

Indices	Arsi Robe	Asasa	Bale Robe	Bekoji	Dhera	Dinsho	Ginir	Kofele	Kulumsa	Sinana
SU25	+1.108**	-4.042**	+0.319*	+0.138*	-0.780**	0.003	+2.153**	0.013	+0.440**	0.162
ID0	0	0	0	0	0	0	0	0	0	0
Tr20	0	0	0	0	-0.008	0	0.008	0	0	0
FD0	-0.003	-1.638**	0	+0.242*	0.005	+0.119*	-0.887**	+0.456*	0	0.012
GSL	0.002	0.002	0.002	0.002	0.002	-0.004	0.002	0.002	0.002	0.002
Txx	+0.057**	-0.140**	+0.041*	+0.081**	-0.019	0.028	+0.066**	0.037	+0.065**	+0.041*
Txn	-0.028*	-0.185	-0.006	0.024	0.017	0.002	-0.037	-0.007	-0.034	+0.053*
Tnx	+0.104**	+0.015**	0.022	+0.102**	-0.065	0.019	+0.228**	-0.086*	0.019	-0.016
Tnn	-0.061**	+0.152**	0.018	-0.130*	-0.087*	-0.073	+0.204**	-0.205**	0.035	-0.002
Tx10p	-0.065	+1.063**	-0.156*	-0.339**	-0.017	-0.370*	-0.434**	-0.048	-0.033	-0.24
Tx90p	+0.342**	-0.615**	+0.304*	+0.543**	-0.164	-0.053	0.187	-0.043	+0.385**	0.122
Tn10p	0.059	-0.466**	-0.143	+0.833*	0.541*	+0.531*	-0.484**	+1.141*	-0.249	0.273
Tn90p	+0.459**	0.317	0.009	+1.037**	-0.099	0.107	+1.281**	0.134	0.007	0.05
WSDI	0.097	-0.53	+0.225*	+0.643**	-0.186	-0.136	0.171	0.14	+0.273*	0.402
CSDI	0.007	-0.626	-0.559*	+2.464*	+0.417*	+1.147*	-0.496**	+3.285*	-0.751**	1.605
DTR	-0.006	-0.258**	0.014	0.033	+0.093*	0.034	-0.188**	+0.129**	0.009	0.033

The **, * shows the trend is significant at $p<0.01$ and 0.05, respectively

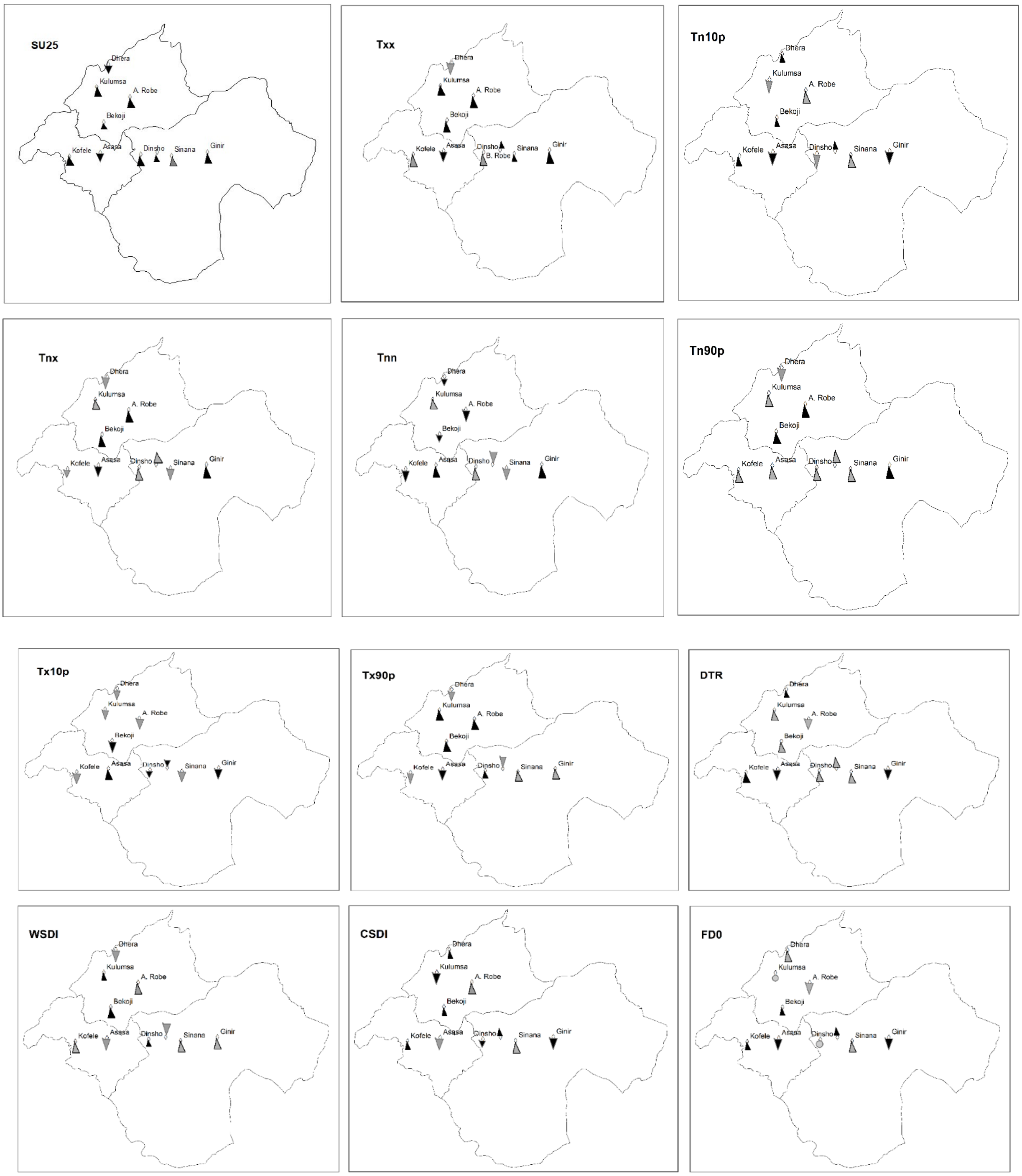

Figure 7: Annual trends and spatial distribution of temperature indices. The upward and downward triangles show increasing and decreasing trends respectively. Significant trends represented by black colored and grey colored ones indicate non-significant trends. The size of the triangles represents the magnitude of the trend.

dicated that, warm extremes are increasing while cold extremes decreasing in most of the study sites. This clearly shows that there has been a warming trend over study area during the study period. Unlike the temperature indices, most of precipitation indices showed decreasing trends and there is no spatial coherence between stations during the study period.

ACKNOWLEDGEMENTS

Our thanks go to the National Meteorology Agency (NMA) of Ethiopia for providing the required climate data used in this study. We would also like to express our gratitude to the Ethiopian Institute of Agricultural Research for funding.

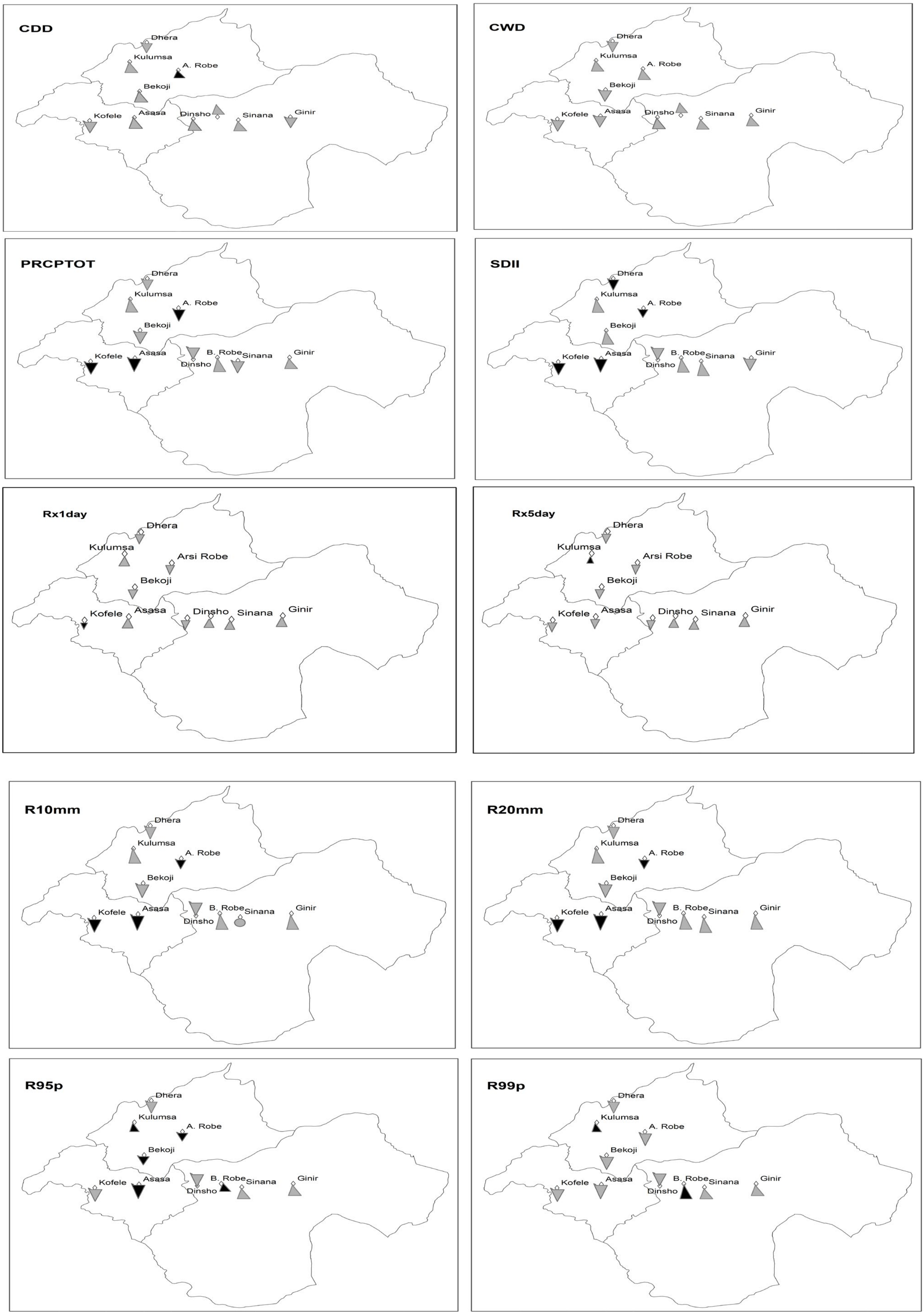

Figure 8: Annual trends and spatial distribution of precipitation indices. The upward and downward triangles show increasing and decreasing trends respectively. Significant trends represented by black colored and grey colored ones indicate non-significant trends. The size of the triangles represents the magnitude of the trend.

Table 4: Trends of precipitation indices.

Indices	Arsi Robe	Asasa	Bale Robe	Bekoji	Dhera	Dinsho	Ginir	Kofele	Kulumsa	Sinana
Rx1day	-0.26	0.02	0.51	-0.23	-0.25	-0.01	0.34	-0.33*	0.41	0.4
Rx5day	-0.35	-0.03	+0.87**	-0.18	-0.46	-0.42	0.3	-0.03	+0.74*	0.15
SDII	-0.07*	-0.04**	0.01	0.02	-0.07**	-0.07	-0.04	-0.05**	0.01	0.03
R10mm	-0.36*	-0.25**	0.09	-0.03	-0.16	-0.56	0.02	-0.45**	0.05	0
R20mm	-0.19*	-0.11**	0.06	-0.08	-0.08	-0.16	0.07	-0.15**	0.06	0.01
R25mm	+0.06*	0.02	+0.03*	0.04	0.04	0.1	0.08	0.04	+0.03*	0.04
CDD	+1.39*	0.71	0.33	0.61	-0.15	0.4	-0.01	-0.16	0.45	0.63
CWD	0.26	-0.11	0.08	-0.03	-0.02	0.14	0.02	-0.07	0.08	0.05
R95p	-4.85*	-2.81**	+3.00*	-3.93*	-1.81	-4.57	0.15	-2.38	+2.85*	0.82
R99p	-2.54	-1.09	+1.92**	-1.72	-0.77	-0.89	0.41	-1.75	+1.91*	0.1
PRCPTOT	-10.26**	-6.12**	3.58	-3.69	-3.57	-10.94	2.04	-9.99**	2.79	-1.43

The **, * shows the trend is significant at $p<0.01$ and 0.05, respectively

REFERENCES

1. Lautze S, Aklilu Y, Raven-Roberts A, Young H, Kebede G, Leaning J. Risk and vulnerability in Ethiopia: Learning from the past, responding to the present, preparing for the future. US Agency for International Development. 2003.

2. Zillman JW. A history of climate activities. World Meteorological Organization (WMO) Bulletin. 2009;58:141.

3. Hansen JW, Zebiak S, Coffey K. Shaping global agendas on climate risk management and climate services: An IRI perspective. Earth Perspect. 2014;1:1-12.

4. Stern R, Rijks D, Dale I, Knock J. INSTAT Climatic Guide. UK: Statistical Services Centre. University of Reading. 2006.

5. Nasher NR, Uddin MN. Maximum and minimum temperature trends variation over northern and southern part of Bangladesh. J Env Sci Natur Res. 2013;6:83-88.

6. Partal T, Kahya E. Trend analysis in Turkish precipitation data. Hydro Pro Int J. 2006;20:2011-2026.

7. Yenigün K, Gümüş V, Bulut H. Trends in streamflow of the Euphrates basin, Turkey. Water Manage. 2008;161:189-198.

8. Hansen JM, Sato J, Ruedy GR. A common-sense climate index: Is climate changing noticeable? Proc Natl Acad Sci. 1998;95:4113-4120.

9. Zhang X, Hegerl G, Zwiers FW, Kenyon J. Avoiding inhomogeneity in percentile-based indices of temperature extremes. J Climatol. 2005b;18:1641-1651.

10. Zewdu TS, Lamb PJ. Characterization and variability of Kiremt rainy season over Ethiopia. Meteor Atmos Phy. 2005;89:153-180.

11. Diga G M (2005) Using seasonal climate outlook to advise on sorghum production in the Central Rift Valley of Ethiopia. University of the Free State, Bloemfontein, South Africa. 2005.