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Observed and Future Climate Variability, Trend and Extremes in Central Highlands of Ethiopia: A Case Study at Arsi Robe, Asasa, Debre Zeit and Kulumsa Areas

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Abstract

The study was conducted with the aim to analyze the variability of onset, cessation and length of growing season, and trends of daily values of temperature and precipitation extremes. The future climate data are downscaled using Marksim weather generator from the outputs of seventeen climate models (GCMs) for 2050s under RCP4.5 and RCP8.5 scenarios. The onset of the rainy season was highly variable than its cessation in the study area during the base period (1981-2015). In this regard, Asasa has experienced high variability of the onset date (CV=37%) followed by Kulumsa (CV=32.6%) and Debre Zeit (CV=32.4%) areas. The mean end of season in the study area was on 256, 298, 272 and 257 DOY at Asasa, Arsi Robe, Debre Zeit and Kulumsa sites, respectively. Analysis of 27 core set of extreme climate indices, which has been developed by ETCCDI is carried out for baseline and future periods, and the results of eighteen of them is discussed in detail in this work. The increase in lowest minimum temperature (TNn) is greater than that in highest maximum temperature (TXx) which represents the coldest or hottest days in a year, season or month respectively. The annual number of days with daily temperature greater than 25°C referred to as summer days (SU25) will be increased highly while the frost days, when minimum temperature is less than 0°C will be decreased in all study sites under both RCPs. Overall, the extreme temperature indices showed that, warm extremes are increasing while cold extremes decreasing in all study sites during mid-century, this series clearly indicate significant warming. From the precipitation extremes, the number of consecutive dry days (CDD) showed decreasing trend under RCP4.5 and increasing under RCP8.5 at Asasa and the reverse trend of this index is observed in Kulumsa area.

Keywords: Climate models; Central highlands; Climate indices; Scenarios; Variability

Introduction

Climate variability and change are among the major environmental challenges of the 21st century [1]. Climate change affect with increased average annual temperatures, reduced and increased variability in rainfall reduces crop yield and threatens food security in low-income and agriculture-based economies [2]. Climate has many obvious implications on landforms and morphodynamic evolution of natural landscapes as much as on the living conditions of local people, in a country whose economy is heavily dependent on rain-fed agriculture [3]. Rainfall and temperature are the most critical variables to agriculture and owed the highest attentions globally. The potential impacts of climate change in Ethiopia are superimposed on stressors such as population pressure, poverty and land degradation [4]. The frequency of climate related shocks and stresses have been increasing from time to time. The increase in frequency of extreme weather events compounded by the difficulty in predicting growing conditions becomes a significant threat for the attainment of food security. Understanding the variability of key characteristics of the rainy season is crucial for Ethiopian agricultural planning in general, and especially for mitigating the adverse effects of recurring drought and capitalizing fully when more abundant rains occur. Because of the complex topography and large spatial rainfall variability a single Kiremt onset criterion could not be established for all of Ethiopia [5].

Changes in climate variability and extremes have received increased attention in recent years, since they can have overwhelming impact on environment and society [6]. Changes in the frequency and severity of extreme climate events and in the variability of weather patterns will have significant consequences for human and natural systems. Hence trend analysis of major climatic variables is vital to forecast the future weather events, its impact on crop production and possible adaptation options. The objectives of this study are to determine the variability of onset, cessation, length of growing season and the probability of dry spell occurrence and to describe trends of extreme climate indices in the central highlands of Ethiopia.

Materials and Methods

Data and quality control

Historical climate data: The long-term (1981-2015) weather data for present climate, hereafter referred to as baseline, of study sites was obtained from the National Meteorology Agency (NMA) and agricultural research centers (Kulumsa and Debrezeit). The missing values were interpolated from neighbor stations using the normal ratio method [7].

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Future climate data: Future climate data was downscaled from ensemble of 17 GCMs namely BCC-CSM1.1, BCC-CSM 1.1 (m), CSIRO_MK3.6, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIRO-ESM-CHEM, MIROC5, MRI-CGCM3, NorESM1-M under RCP4.5 and RCP8.5 using MarkSim weather generator [8] which have been statistically bias-corrected [9].

Data quality control: Data homogeneity was assessed with the RH Test V4 software, which uses a two-phase regression model to check for multiple step change points that could exit in a time series [10-12]. The temperature data was checked for gross errors and outliers using the quality control procedures of the Microsoft Excel-based RClimDex software Figure 1 [13].

Methodology

Onset, cessation, and length of growing season: In this study, a day with first wet spell of at least three days accumulating 20 mm or more after specified date (in this case 1st March), provide that there were no sequences of 9 or more dry days (<1 mm) in the subsequent 30 days was adopted [14-16]. Similarly the cessation date was determined based on the definition, the season ends when the water stored in the soil has been used, rather than when the rainfall stops with the earliest possible day of 1st September. The capacity of soils to persist precipitation with a water balance equal to zero is 100 mm [17]. The evapotranspiration data is another tool to determine the cessation of the season, the daily reference evapotranspiration (ET_o) data was estimated from maximum and minimum temperature using the Hargreaves ET_o equation due to the existing limited climatic variables.

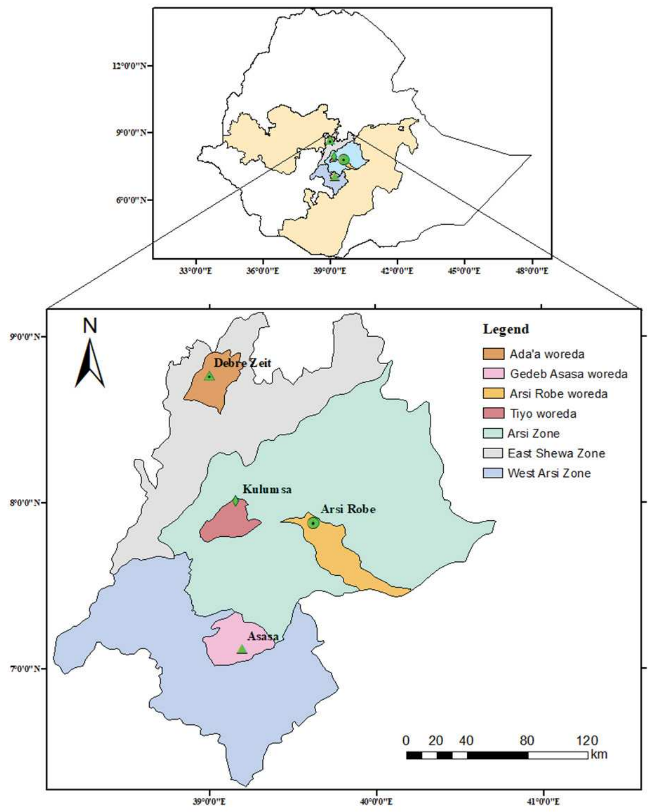

Figure 1: Location map of the study area.

$$ET_o=0.0023(T_{mean}+17.8)\,(T_{max}-T_{min})\,0.5\,Ra \quad (1)$$

The length of growing season was calculated as the difference between the onset and cessation date of the season. The period includes the duration of the time that 100 mm of soil moisture reserve has already been evapotranspired after the end of the rainy season [18,19].

Trend analysis of rainfall and temperature characteristics: Trend Test: in this particular study, Mann-Kendall trend test was employed to detect the trend of climate variability. Mann-Kendall's test is a non-parametric test for identifying trends in time series data, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear [20]. The test compares the relative magnitudes of sample data rather than the data values themselves, and it is the most widely used method since it is less sensitive to outliers and it is the most robust as well as suitable for detecting trends in precipitation [21].

Analysis of climate extremes: 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 [22]. Sixteen of these indices are temperature related and eleven are precipitation related. They are derived from daily maximum and minimum temperature and daily precipitation. All 27 core indices were calculated using RClimDex software and only 18 of them were discussed in this work Table 1. A bootstrapping method proposed by Zhang et al. [23] has been implemented in RClimDex and is used to compute indices analyzed in this study. The bootstrap procedure removes the in homogeneities and thus eliminates possible bias in the trend estimation of the relevant indices. Annual trends of all indices are tested for statistical significance at the 5% confidence level for each study sites.

Results and Discussion

Variability and trends of climate events and extremes for base period

Onset and cessation of the rainy season: Analysis of long term (1981-2015) rainfall data revealed that the mean rainfall onset dates were to be on the third dekad of March at Arsi Robe, second dekad of April at Kulumsa and the first dekad of May at Asasa and Debre Zeit areas Table 2. Arsi Robe has the earliest onset of rainy season during the 3rd dekad of March whereas the latest onset was found to be in the first dekad of May at Asasa and Debre Zeit areas. The earliest onset of rainy season was on March 2nd, 3rd, 5th and 16th at Kulumsa, Asasa, Debre Zeit and Arsi Robe, respectively, and extended to a maximum of July 1st at Kulumsa, July 13th at Arsi Robe and July 18th at Asasa and Debre Zeit areas. Generally, start of the rainy season in the study area was highly variable. In this regard, Asasa has experienced high variability of the onset date (CV=37%) followed by Kulumsa (CV=32.6%) and Debre Zeit (CV=32.4%) areas Table 2. This implies that, estimation of start of the season for the study area could be difficult than information regarding the end of the season. According to Raes et al. [24] defining the onset date of the rainy season can sometimes be very challenging, as the onset characteristics can vary drastically with isolated showers or heavy rainfall of varying intensity being accompanied by extended dry spells. Therefore, it is difficult to advise farmers regarding to the onset of rainy season related information like when, what and how to plant and other information relating to agriculture precision for their better livelihood. Overall, the onset of rainy season was highly variable as compared to the end of the season, which is comparable to the previous work over Ethiopia [25]. On the other hand, the season ceased early on September 2nd (245 DOY) at Asasa and Kulumsa areas, September

	Indices	Indicator name	Definitions	Units
Temperature indicators	CSDI	Cold spell duration indicator	Annual count of days with at least 6	Days
			consecutive days when TN<10th percentile	
	FD0	Frost days	Annual count when TN(daily minimum)<0°C	Days
	SU25	Summer days	Annual count when TX>25°C	Days
	TN90p	Warm nights	Percentage of days when TN>90th percentile	%
	TX90p	Warm days	Percentage of days when TX>90th percentile	%
	TN10p	Cool nights	Percentage of days when TN<10th percentile	%
	TX10p	Cool days	Percentage of days when TX<10th percentile	%
	WSDI	Warm spell duration indicator	Annual count of days with at least 6	Days
			consecutive days when TX>90th percentile	
	TXx	Max Tmax	Monthly maximum value of daily Tmax	°C
	TNx	Max Tmin	Monthly maximum value of daily Tmin	°C
	TXn	Min Tmax	Monthly minimum value of daily Tmax	°C
	TNn	Min Tmin	Monthly minimum value of daily Tmin	°C
Precipitation indicators	CDD	Consecutive dry days	Maximum number of consecutive days with	Days
			RR<1 mm	
	CWD	Consecutive wet days	Maximum number of consecutive days with	Days
			RR>=1 mm	
	R95p	Very wet days	Annual total PRCP when RR>95th percentile	mm
	R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
	PRCPTOT	Annual total wet day precipitation	Annual total PRCP in wet days (RR ≥ 1 mm)	mm
	SDII	Simple daily	Annual total precipitation divided by the	mm/day
		intensity index	number of wet days (defined as	
			PRCP ≥ 1.0 mm) in the year	

Table 1: Definition of extreme climate indices.

4th (247 DOY) at Debre Zeit and September 8th (251) at Arsi Robe. The soeson was late end on October 18th (291 DOY), 21st (194 DOY), 26th (299 DOY) and November 25th (325 DOY) at Debre Zeit, Asasa, Kulumsa and Arsi Robe areas, respectively, Table 2. The mean end of season in the study area was on 256, 298, 272 and 257 DOY at Asasa, Arsi Robe, Debre Zeit and Kulumsa sites, respectively. Moreover, the rain would ceased twice in a four years on 10th September, 3rd October, 23rd October and 6th September at Asasa, Arsi Robe, Debre Zeit and Kulumsa areas, respectively Table 2.

Length of Growing Season (LGS): The length of the rainy season in any given area is influenced by the onset and cessation dates. This study indicated that there is a significant relationship between the onset of rain and the length of the rainy season in all locations; earlier onset most often leads to longer rainy season. This is an indication that the length of the rainy season is more dependent on the rainfall onset than its cessation. Meaning that, the LGS was strongly influenced by onset of rainfall than its cessation in the study sites. The mean length of growing season for the study period (1981-2015) at the study areas are depicted in Table 2. The mean lengths of growing seasons were respectively, 123, 183.7, 152.8 and 156.4 days at Asasa, Arsi Robe, Debre Zeit and Kulumsa areas. This indicated that a crop requires length of growing season of up to 123, 183, 152 and 156 days could be produced with low risk of water shortage in Asasa, Arsi Robe, Debre Zeit and kulumsa areas, respectively. Furthermore, the LGS shows negative trends at all areas but none of them is statistically significant Table 2. These results suggest that the later onset of rainfall was in most cases compensated by later cessation.

Number of rainy days: The mean number of rainy days with their standard deviations and coefficient of variation were presented in Table 2. The number of rainy days was less than 94 days at Asasa, 131 days at Arsi Robe, 95 days at Debre Zeit and 120 days at Kulumsa once in four years (25% probability). Moreover, the number of rainy days would be less than 117, 155, 122 and 138 days at Asasa, Arsi Robe, Debre Zeit and Kulumsa areas, respectively in three out of four years (75% probability) Table 2. The minimum and maximum numbers of rainy days at study sites were 68 and 150 days at Asasa, 104 and 195 days at Arsi Robe, 87 and 197 days at Debre Zeit and 84 and 227 days at Kulumsa areas. This shows the inter-annual variability of number of rainy days was very high which can affects the seasonal rainfall amounts that could be received by the area and in turn affects available water to the plants. In this regard, Debre Zeit has experienced high variability of number of rainy days (CV=24.6%), whereas less variable at Kulumsa (CV=10.5%) Table 2. The number of rainy days showed decreasing trends in all study sites though none of the tried is statistically significant. The number of rainy days might be affected by both onset and cessation dates of the season. Meaning that, the number of rainy days increased with early onset and late cessation and vice versa.

Probability of dryspell occurrence: Figure 2 shows the probability of dry spell lengths of 5, 7, 10 and 15 days of the study sites. The graph showed that the probability of occurrence of dry spell of all lengths is less than 20% at the middle of growing season in all study areas. It could be seen from the graph that the probability of 10 and 15 days dry spell lengths were fall below 5% after 140 DOY (May 20th) at Arsi Robe, 180 DOY (June 29th) at Asasa and 160 DOY (June 9th) at Debre Zeit and Kulumsa areas. The graph also indicated that the probability of 7 day dry spell is dropped below 5% after 160 DOY at Arsi Robe, 180 DOY at Debre Zeit and Kulumsa while the probability is greater than 5% all through the season at Asasa area. Moreover, the probability of 5 day dry spell is greater than 10% all throughout the season at all locations while the longer dry spells have less than 10% probability of occurrence at the middle of growing season Figure 2. This implies that, the risk from the longer dry spells (7, 10 and 15 days) is less at the middle of the season that could be conducive for wheat production in the area for smallholder farmers who have no access to supplementary irrigation. On the other hand, the probability of longer dry spells increased swiftly as of 3rd dekad of August and take risks of longer dry spells for the study periods at all study sites Figure 2. Thus, unless there is access to supplementary irrigation and/or other risk minimizing options it could be a harsh condition for crop production. Therefore, selection of

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Station	Rainfall Features	Min.	Quartile1 (25%)	Median -50%	Quartile3 (75%)	Max.	Mean	SD (±)	CV (%)	Z_{MK}	P_value	Slope
Asasa	SOS(DOY)	62	86	98	86	199	122	45.28	37	0.89	0.371	0.467
	EOS(DOY)	245	248	253	260	294	256	11.73	4.6	-0.93	0.351	-0.154
	LGS(days)	50	80	133	160	213	123	45.7	37	-1.07	0.287	-0.933
	NRD(days)	68	94	104	117	150	106.2	19.7	18.6	-0.68	0.497	-0.273
	TSRF(mm)	162	340	446.6	493.4	760.9	426.3	130.9	30.7	-2.54*	0.011	-5.564
Arsi Robe	SOS(DOY)	75	89	103	89	194	114	35.72	31.3	0.73	0.467	0.148
	EOS(DOY)	251	288	296	309	325	298	16.46	5.5	-0.4	0.69	-0.118
	LGS(days)	69	160	192	221	242	183.7	41.87	22.8	-0.9	0.369	-0.485
	NRD(days)	104	131	142	155	195	143.9	22.49	15.6	-1.66	0.098	-0.857
	TSRF(mm)	436.9	619	772.6	943.6	1391	798.3	253.1	31.7	-2.38*	0.017	-10.681
Debre Zeit	SOS(DOY)	64	81	126	81	199	120	38.74	32.4	0.71	0.478	0.333
	EOS(DOY)	247	265	276	280	291	272	10.82	4	-0.66	0.51	-0.071
	LGS(days)	65	118	154	192	222	152.8	42.89	28.1	-0.6	0.548	-0.429
	NRD(days)	87	95	110	122	197	115	28.32	24.6	-1.66	0.097	-0.5
	TSRF(mm)	273	581.4	689.5	768.6	1089	687.9	174.6	25.4	-0.34	0.73	-0.856
Kulumsa	SOS(DOY)	61	72	96	72	182	101	32.85	32.6	1.39	0.163	0.583
	EOS(DOY)	245	245	249	268	299	257	14.73	5.7	0.85	0.396	0.053
	LGS(days)	84	135	159	184	227	156.4	33.7	21.5	-0.52	0.602	-0.2
	NRD(days)	96	120	127	138	151	128.4	13.5	10.5	-0.15	0.882	-0.111
	TSRF(mm)	311.2	457.3	581.2	689.6	896.9	579.5	145.3	25.1	0.23	0.815	0.346

Note. SOS, Onset date; EOS, cessation date; LGS, length of growing season; NRD, number of rainy season; TSRF, total seasonal rainfall; SD, standard deviation; CV, coefficient of variation; DOY, days of year; $Z_{MK,}$ Mann-Kendall's trend test

Table 2: Trends and descriptive statistics of rainfall characteristics of the study areas during the study period (1981-2015).

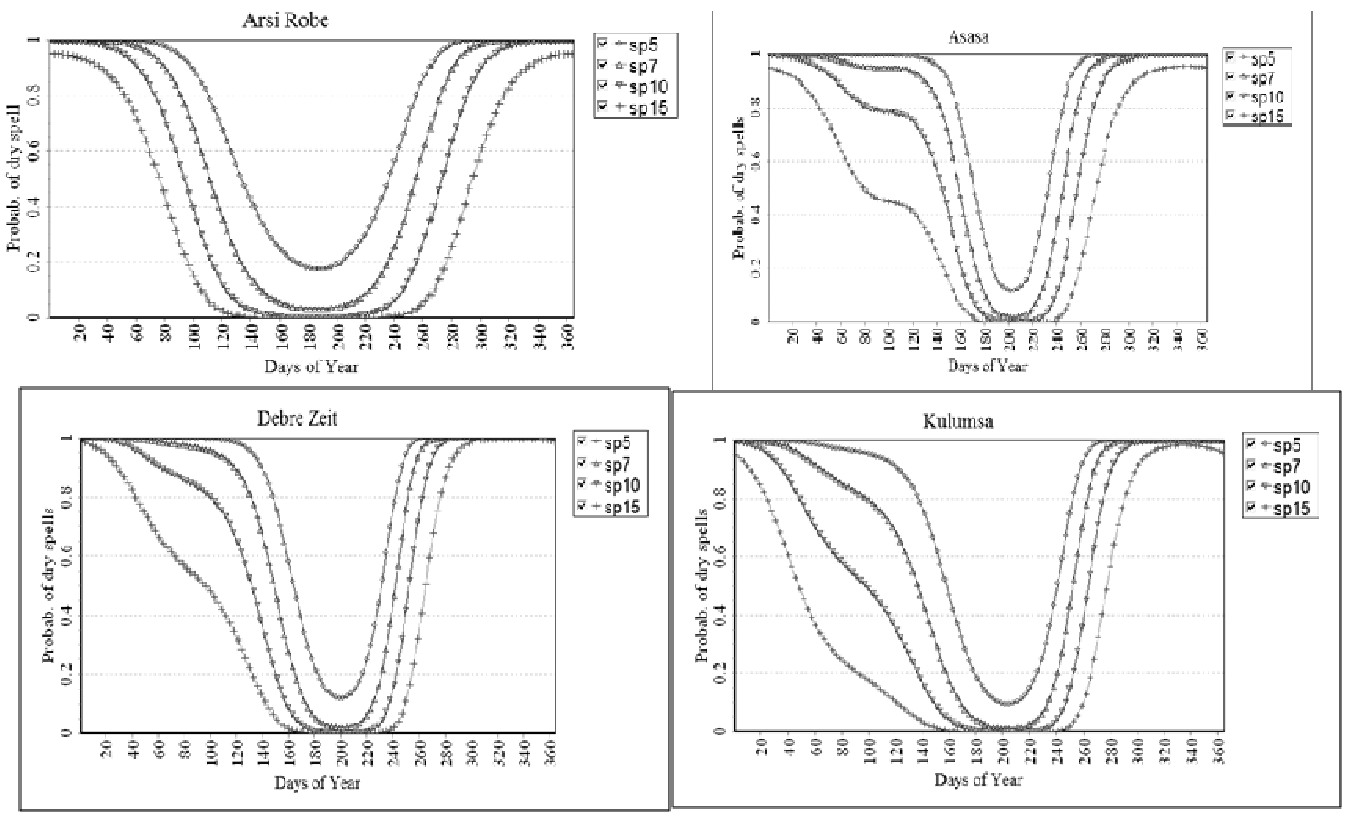

Figure 2: Probability of dry spell lengths of 5, 7, 10 and 15 days at Arsi Robe, Asasa, Debre Zeit and Kulumsa areas during the base period (1981-2015).

drought tolerant cultivars and early planting should be possible options for non-risk taker (risk averse) farmers to minimize losses as a result of longer dry spells occurred at end of the season.

Annual and seasonal rainfall variability: The seasonal and annual total rainfall decreased in almost all study sites during the study period (1981-2015) Table 3. The contribution of longer rainy season (Kiremt) to the annual rainfall total is respectively, 55%, 65%, 74% and 55% at Arsi Robe, Asasa, Debre Zeit and Kulumsa whereas the shorter rainy season (Belg) and dry season (Bega) are contribute less. The annual rainfall totals of Belg and Bega seasons were highly variable compared to annual and Kiremt rainfall totals. The coefficient of variation (CV) value of the mean of main rainy season (Kiremt) is very small as compared with that of Belg and Bega seasons at all locations Table 3. This shows that kiremt rainfall was less variable than that of Belg and Bega seasons over study area. Coefficient of variation is used to classify the degree of variability of rainfall events as less, moderate and high. When CV<20% it is less variable data wise, CV from 20% to 30% is moderately variable, and CV>30% is highly variable. Areas with CV>30% are said to be vulnerable to drought (Hare, 1983). Based on this classification the Kiremt and annual rainfall totals are less to moderately variable whereas, Belg and Bega rainfall are highly variable in all study sites.

There is a decreasing trend in Belg seasonal rainfall and annual rainfall totals in all study sites, but the trend was statistically significant in Arsi Robe and Asasa areas. It is also noted that Kiremt rainfall showed increasing trend in Arsi Robe and Kulumsa and decreased over Asasa and Debre Zeit areas whereas Bega rainfall was decreased in Asasa and Arsi Robe, and increased at Debre Zeit and Kulumsa sites, however, none of the trend was statistically significant.

Analysis of climate extremes for base period:

Temperature extremes: Trends for some selected temperature and precipitation indices are presented in Table 4. As it could be observed from the table, the number of summer days (SU25), averages of warm night frequency (TN90), warm day frequency (TX90) and warmest night temperature (TNx) also display the warming trends during the period. A number of days with maximum temperature greater than 25°C (SU25) was strongly increased in 1.2, 1.03, 1.07 days/year at Arsi Robe, Debre Zeit and Kulumsa areas, respectively, while decreased in 4.11 days/year at Asasa area Table 4. The trend was significant at the 5% level of confidence in all study areas except Kulumsa. Moreover, the frequencies of warm days and nights, increased over Arsi Robe, Debre Zeit and Kulumsa areas. The number of days per year exceeding the 90th percentile threshold was highly decreased at Asasa area. Similarly the monthly maximum value of daily maximum (TXx) displayed significantly increasing trend at Arsi Robe, Debre Zeit and Kulumsa areas whereas significantly decreased at Asasa area. The monthly maximum value of minimum temperature (TNx) showed insignificantly increasing trend at all study sites except Arsi Robe. The warm spell duration (annual count of days with at least 6 consecutive days when TX>90th percentile) showed increasing trends for Arsi Robe, Debre Zeit and Kulumsa while decreasing over Asasa area. However, the trend was non-significant at all study sites Table 4. The number of warm days (Tx90p) and nights (Tn90p) were increased in almost all sites while the number of cold days (Tx10p) was decreased.

On the other hand, the monthly minimum value of maximum daily temperature (TXn) decreased significantly at Arsi Robe and Asasa while the trend was insignificantly decreased at Debre Zeit and Kulumsa areas. There was a decreasing trend of monthly minimum value of daily minimum temperature (TNn) at all study sites except Asasa. The trend was significant at Arsi Robe and Debre Zeit areas whereas non-significant at Kulumsa site. The cold spell duration (CSDI) have showed negative trends for the two sites (Arsi Robe and Asasa) and positive trends over the rest two areas (Debre Zeit and Kulumsa) with non-significant trends in all study sites except Debre Zeit Table 4.

Precipitation extremes: The maximum number of consecutive days with less than 1 mm rainfall (CDD) was increased over all study sites whereas the maximum number of consecutive days with rainfall of greater than 1 mm (CWD) showed decreasing trend at all study sites except Kulumsa, however, none of the trend was statistically significant. The simple daily precipitation intensity index (SDII) indicated decreasing trends at Arsi Robe and Asasa while increased over Debre Zeit and Kulumsa areas and the trend was significant at all sites except Kulumsa. Similarly, the two annual total precipitation extremes when rainfall > 95th and 99th percentile showed decreasing trend over Arsi Robe and Asasa while increasing at Debre Zeit and Kulumsa. The trend was statistically significant at Arsi Robe and Asasa and non-significant at Debre Zeit and Kulumsa for very wet days (R95p) whereas nonsignificant at all study sites for extremely wet days (R99p) Table 4. The annual total wet day precipitation showed a decreasing and significant trend over all study sites with high decreasing values 12.48 mm/year and 6.77 mm/year at Arsi Robe and Asasa, respectively Table 4.

Changes and trends of future climate

Mean annual rainfall: The projected annual total rainfall will be expected to increase in all study sites under RCP4.5 and RCP8.5 by mid-century (2050s) compared to the baseline period (1980-2009). The change in projected annual total rainfall is depends on the concentration type meaning annual rainfall total will be expected to be changed more under high concentration pathway (RCP8.5) compared to medium concentration pathway (RCP4.5) at Arsi Robe and Asasa areas. However, the change will be higher under RCP4.5 than under RCP8.5 at Debre Zeit and Kulumsa.

Overall the annual total rainfall will be expected to increase in all study sites under both scenarios compared to the base period. The result of this study is line with what has been projected by IPCC (2013) [26] who reported probable increase of rainfall by 20-30% in East Africa including Ethiopia. Intergovernmental Pannel on Climate Change (IPCC) also reported that there will be an increase of up to 40% in annual runoff for East Africa due to increased precipitation in the region. This extreme rainfall might be resulted in decreased agricultural yields due to more flooding events in the region [27-29].

Mean seasonal rainfall: Kiremt rainfall will be expected to increase by 11.7 and 11.8% at Arsi Robe; 21.9 and 31.2% at Asasa; 37.4 and 37% at Debre Zeit and 64.5 and 57.7% at Kulumsa under RCP4.5 and RCP8.5, respectively. Similarly, an increasing trend of shorter rainy season (Belg) rainfall will be expected under both RCPs in all study sites except Arsi Robe by 2050s. The dry season (Bega) rainfall will be expected to decrease under both scenarios in Asasa and Debre Zeit sites while increased at Arsi Robe area. There will be much more increment of Belg rainfall than that of Kiremt season at Asasa under both RCPs while the reverse is true for Kulumsa area. Overall, much amount of Belg (FMAM) rainfall will be expected by midcentury under both RCP scenarios than the average rainfall received by the area from Belg (FMAM) season previously in all study sites except Arsi Robe. Generally, precipitation projections suggest seasonal rainfall will change in all locations though the direction and magnitude of change varies with location than that of annual rainfall.

Station	Parameter	Minimum (mm)	Maximum (mm)	Mean(mm)	SD(±)	CV%	Z_{MK}	P_value	Slope	Trend
Arsi Robe	Kiremt RF	386.3	951.8	560.1	144.1	25.7	0.08	0.932	0.533	increasing
	Belg RF	128.8	817.75	347.6	158.9	45.7	-2.19*	0.029	-5.1	decreasing
	Bega RF	13.1	387.7	127.25	84.42	66	-0.21	0.831	-0.121	decreasing
	Annual RF	644.5	1418.5	1020.3	207.6	20	-2.95**	0.003	-10.359	decreasing
Asasa	Kiremt RF	297.5	634.6	414.1	86.8	21	-0.82	0.41	-1.483	decreasing
	Belg RF	42	326	161.5	81.7	50.6	-2.33*	0.02	-3.49	decreasing
	Bega RF	4.5	388.9	72.19	77.58	70	-0.43	0.665	-0.5	decreasing
	Annual RF	359.1	1052.5	641.7	144.1	22	-2.64**	0.008	-5.767	decreasing
Debre Zeit	Kiremt RF	385.1	804	603.9	98.6	16.3	-0.47	0.638	-0.991	decreasing
	Belg RF	49.7	461	190	94.2	49.6	-0.98	0.326	-1.576	decreasing
	Bega RF	0	138.6	36.93	40	80	0.68	0.498	0.438	increasing
	Annual RF	595.5	1123	817	124.3	15	-0.69	0.49	-1.58	decreasing
Kulumsa	Kiremt RF	297.8	733.9	449.6	77.3	17.2	0.48	0.632	0.492	increasing
	Belg RF	125.2	446.9	292.2	102.7	35.1	-1.63	0.102	-3.025	decreasing
	Bega RF	12.4	216.2	81.3	58.57	72	0.68	0.498	0.805	increasing
	Annual RF	596.3	984	823.1	99.8	12	-0.76	0.447	-1.083	decreasing

Table 3: Descriptive statistics and Mann Kendall's trend tests of annual and seasonal rainfall totals of study areas during 1981-2015.

	Arsi Robe		Asasa		Debre Zeit		Kulumsa	
Index	Slope	P-Value	Slope	P-Value	Slope	P-Value	Slope	P-Value
SU25	+1.2**	0	-4.11**	0	+1.03**	0.009	1.07	0.061
FD0	0.02	0.269	-1.83**	0	0.02	0.25	0.01	0.14
TXx	+0.07**	0.005	-0.14**	0	+0.09**	0.002	+0.05*	0.048
TNx	+0.16**	0	0.03	0.488	0.01	0.592	0	0.951
TXn	-0.05**	0.005	-0.19**	0	-0.04	0.352	-0.03	0.152
TNn	-0.1**	0	+0.19**	0.001	-0.12**	0.002	-0.06	0.104
Tx90p	+0.4**	0.004	-0.6**	0	+0.41**	0.003	0.29	0.088
Tn90p	+0.5**	0	0.37	0.095	0.19	0.13	0.26	0.215
Tx10p	-0.01**	0	+1.19**	0	-.22**	0.002	-0.1	0.25
Tn10p	0.1	0.469	-.47*	0.012	+0.35*	0.016	+0.42*	0.019
WSDI	0.28	0.151	-0.49	0.148	0.24	0.114	0.44	0.188
CSDI	-0.06	0.603	-0.48	0.257	+0.34**	0	0.1	0.053
SDII	-0.09**	0.007	-0.04**	0.008	+0.09*	0.013	0	0.934
CDD	0.06	0.899	0.74	0.203	0.92	0.184	0.44	0.327
CWD	-0.08	0.302	-0.12	0.246	-0.12	0.141	0.01	0.757
R95p	-6.66*	0.017	-3.61**	0.005	0.94	0.606	0.25	0.823
R99p	-3.58*	0.025	-1.43	0.09	0.93	0.436	0.65	0.412
PRCPTOT	-12.48**	0.009	-6.77**	0.003	-1.35	0.549	-1.12	0.512
**,* The trend is statistically significant at 1 and 5% probability level.								

Table 4: Annual trends of temperature and precipitation extremes for base period.

Mean monthly rainfall distribution: Figure 3A-D show the projected mean monthly rainfall distribution of 2050s under RCP4.5 and RCP8.5 scenarios and baseline period (1980-2009) for Arsi Robe, Asasa, Debre Zeit and Kulumsa areas, respectively. It could be clearly seen from the figure that future rainfall will increase considerably during the months of May and July as compared to that of the baseline period. In both months, rainfall will increase in 2050s regardless of the climate scenarios considered. On the other hand, the mean minimum and maximum monthly rainfall will be expected in the month of November and July in all study sites by the midcentury while for the baseline period it was in December and August, respectively, Figure 3. This shows that there will be temporal shifts of maximum and minimum mean monthly rainfall from the baseline period in all areas under both scenarios. In general there will be slight temporal shift of mean monthly rainfall distribution in both Kiremt (JJAS) and Belg (FMAM) rainy seasons by 2050s under both RCPs.

Rainfall projection during wheat growing season: The highest rainfall during wheat growing season/window is in July under both RCPs while gets its peak in the month of August during the baseline period in all study sites. This shows that, there will be temporal shifts from baseline period of maximum mean monthly rainfall during the mid-century under high and medium concentration scenarios. The mean monthly rainfall of June will be decrease in all sites except Asasa whereas the mean monthly rainfall of July will dramatically increase in all study sites under both RCPs during the midcentury Figure 4. Therefore, this could enhance wheat productivity in the study sites as a lot of water will be stored in the soil. In contrast to this, mean monthly rainfall of September and October will be decrease under both scenarios for the time slice over all study sites compared to the baseline period Figure 4. This could negatively affect wheat productivity in the study area because these two months are critical (flowering and grain filling) period when enough rainfall is required. This result is consistant

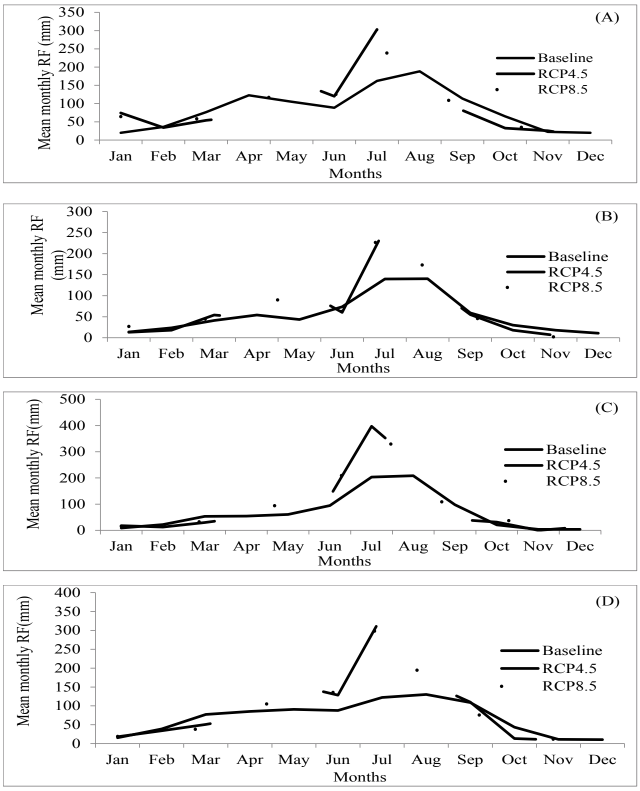

Figure 3: Comparison of mean monthly rainfall of baseline period with model predicted under RCP4.5 and RCP8.5 in the study sites (A: Arsi Robe; B: Asasa; C: Debre Ziet and D: Kulumsa).

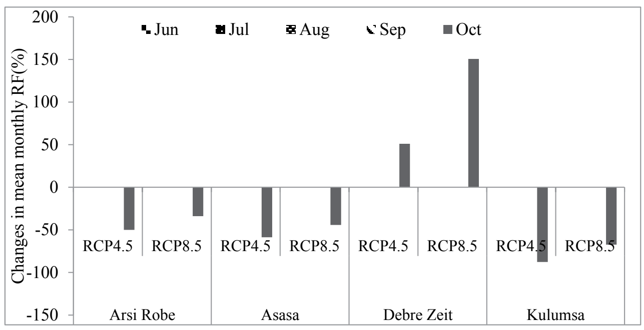

Figure 4: Changes in mean monthly rainfall distribution for wheat growing months by 2050s compared to the baseline period in the study area.

with Cairns et al. [30] who reported that, the rainfall will decrease in 2050s during the growing season (May-October) particularly during the critical reproductive stage over the highlands of Ethiopia. This indicates that, wheat production will be possible by 2050s under the changing climate by adjusting the planting time and other management practices accordingly.

Mean annual air temperature change: Mean annual air temperature will increase in all study sites under the considered RCPs by 2050s. More increments of air temperature will be expected under the high concentration scenario (RCP8.5) than under medium concentration scenario (RCP4.5) compared to the baseline period (1980-2009) in all sites. The result revealed that the mean air temperature will increase by 1.98 and 2.2°C at Arsi Robe; 1.9 and 2.14°C at Asasa; 1.67 and 1.9°C at Debre Zeit and 1.85 and 2.06°C at Kulumsa under RCP4.5 and RCP8.5, respectively during 2050s. This is lined with the reports of intergovernmental panel on climate change [26] who reported that, the average temperature will increase in 2-3°C by the mid-century and 4-6°C by end of 21st century over East Africa including Ethiopia.

There are high levels of confidence of climate models in projecting continuing temperature increases in Ethiopia, though the extent of the rises depends on emissions scenarios and varies between models [31]. This might benefit wheat productivity by enhancing photosynthesis with respective rainfall increment in the study area. In contrast to this it might enhance the infestation of disease and pests and also increase evapotranspiration loss which may affect the productivity of wheat. More than half of wheat production areas worldwide already experience heat stress and increased temperatures during some part of the crop growth cycle might negatively affect its productivity [32]. All of these findings point to the need to understand the effects that rising temperatures will have on wheat growth in the future. Any temperature increase will increase rates of evapotranspiration, possibly leading to a deficit in the water balance and posing a major challenge to rain fed agriculture.

Temperature projection during wheat growing season: There will be an increment in mean monthly air temperature under both scenarios during wheat growing season over the study area. The highest temperature during wheat growing months will be in June in all study sites by the mid-century. In July and August, there will per decade increase of 0.13 and 0.11°C at Arsi Robe, 0.1 and 0.12°C at Asasa, 0.05 and 0.12°C at Debre Zeit and 0.1 and 0.15°C at Kulumsa of air temperature respectively, under RCP4.5. The mean air temperature of September and October will also increase by 0.14°C and 0.16°C, 0.15 and 0.13°C and 0.11 and 0.13°C at Asasa, Kulumsa, Arsi Robe and Debre Zeit per decade, respectively, under the same scenario while more increament will be expected under RCP8.5 by 2050s. This increment in air temperature might affect the rate of photosynthesis and evapotranspiration which in turn affects the productivity of wheat in the study area. Temperature events higher than normal are expected to reduce cereal yields. For example, elevated temperatures are known to shorten the grain-filling period, reduce pollen viability and weight gain in grain [33,34].

Moreover, temperature changes can result in warmer, less severe winters, which sometimes allow diseases and pests to survive and overwinter, increasing the likelihood of reduced yield during the next cropping season. This in turn leads to a wide application of agricultural pesticides. The use of pesticides in agricultural production can improve yield as well as the quality of the produce. They can also improve the nutritious value and safety of crops. But despite these advantages, inappropriate application or excessive use of pesticides can cause several negative side effects. Especially, pesticide contamination of crops can negatively affect human health. Pesticides have been involved in a wide range of human health hazards such as headaches and nausea, chronic impacts like cancer, reproductive harm and endocrine disruption [35]. Furthermore, the usage of these chemicals, especially organochlorine pesticides has occasionally been accompanied by risks to human health and the environment because of their toxic potential, high persistence, bioconcentration, and, especially, their non-specific toxicity [36]. The residues of chlorinated pesticides in food have given rise to major concerns especially when these commodities are freshly consumed [37,38]. Exposure to pesticide residues through the diet is assumed to be five orders of magnitude higher than other exposure routes, such as air and drinking water [39]. Therefore, this implies that, climate and temperature changes can affect crop production directly by affecting

		Arsi Robe		Asasa		Debre Zeit		Kulumsa	
	Index	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Temperature Indices	SU25	1.051**	2.007**	1.4**	2.163**	.327**	1.036**	0.7**	1.591**
	FD0	-.084**	-.196**	-.112*	-.126**	0	-.049*	-.041**	-.057**
	TXx	0.022**	0.047**	.031**	.036*	.029**	.11**	.022**	.049**
	TXn	0.024**	0.052**	.033**	.044**	.028**	.054**	.022**	.06**
	TNx	0.015**	0.03**	.016**	.029*	.014**	.029**	.011**	.03**
	TNn	0.035**	0.078**	.041**	.082**	.035*	.083**	.025**	.076**
	TX90p	0.9**	0.934**	.897**	.972**	.831**	.96**	.501**	.961**
	Tn90p	0.825**	0.874**	.813**	.879**	.741**	.897**	.56**	.913**
	TX10p	-0.867*	-0.925*	-.728*	-.904**	-0.825	-0.923	-0.64**	-0.874*
	Tn10p	-0.847*	-0.968*	-.842**	-.99*	-0.897*	-0.964*	-0.816*	-0.955*
	WSDI	0	0	0	0	0	0	0	0
	CSDI	0	0	0	0	0	0	0	0
Precipitation Indices	SDII	-.013**	-.032**	.049**	.081**	0.013	.068**	-0.027	-.042**
	CDD	0	0	-0.033	1.178**	0	-0.051	0.058	-0.014
	CWD	0.037*	0	-0.013	-.078**	0	.096**	.067**	.119**
	R95p	0.102	-4.83**	4.334**	6.511**	0.715	0.811	2.612	-2.023
	R99p	1.567**	2.103**	-0.574	2.675*	1.841**	-0.817	-1.301	-2.671**
	PRCPTOT	1.396**	1.393*	2.016**	2.847**	-0.056	0.71	3.683*	-0.689
**,* The trend is significant at 0.01, 0.05 confidence level									

Table 5: Annual trends of temperature and precipitation extremes during the midcentury under RCP4.5 and RCP8.5.

rate of photosynthesis and evapotranspiration, and indirectly through disease and pest infestation which in turn affects human health and environment.

Analysis of climate extremes for future period:

***Temperature extremes*:** Trends in temperature indices reflect warming tendency of the study area regardless of scenarios considered during the mid-century. The increase in lowest minimum temperature (TNn) is greater than that in highest maximum temperature (TXx) which represents the coldest or hottest days in a year, season or month respectively. The average increase in TNn and TXx projected by the mid-century respectively is 0.08 and 0.03°C in Arsi Robe and Asasa and 0.08 and 0.04°C in Debre Zeit and Kulumsa per year Table 5. The annual number of days with daily temperature greater than 25°C referred to as summer days (SU25) will be increased highly while the frost days, when minimum temperature is less than 0°C will be decreased in all study sites under both RCPs. The frequency of days and nights warmer than the 90th percentile (Tx90p and Tn90p) will be expected to increase whereas the frequency of cold days (Tx10p) and nights (Tn10p) decreased significantly under both scenarios with more increment/decrement values under high concentration scenario (RCP8.5) Table 5. Overall, the warm extremes are increasing while cold extremes decreasing, these series clearly indicate significant warming over study area and individual stations show most spatial coherence in all temperature indices. Moreover; there is no trend in both warm and cold duration indices in all study sites under both RCPs Table 5. This temperature increment might enhance wheat productivity in the study area through increasing rate of photosynthesis with the respective total precipitation increment to some extent. However, more increment of minimum and maximum temperature could reduce wheat yields considerably by increasing rate of respiration and damaging crop reproductive organs [40].

***Precipitation extremes*:** In contrast to that of temperature indices there is no spatial coherence between individual stations in projections of precipitation indices. For instance, the annual total wet day precipitation will be expected to increase under both scenarios at Arsi Robe and Asasa areas. It will be decrease under RCP4.5 and increase under RCP8.5 at Debre Zeit area while increase under RCP4.5 and decrease under RCP8.5 at Kulumsa Table 5. However, the total annual precipitation will be expected to increase in all study sites except kulumsa compared to the baseline period. The number of consecutive dry days (CDD) showed decreasing trend under RCP4.5 and increasing under RCP8.5 at Asasa and the reverse trend of this index is observed in Kulumsa area [41]. The simple daily intensity index (SDII), which takes into account the number of days with rainfall greater than or equal to 1 mm, shows decreasing trend in Arsi Robe and Kulumsa while increase in Asasa and Debre Zeit areas under both RCPs. Compared to the temperature indices, the trends of precipitation indices are less significant in the study area Table 5. This confirms the results of Conway and Schipper (2011) [31] who reported that climate models have high level of confidence in projecting changes in temperature than precipitation.

Summary and Conclusion

Past climate characterization was carried out based on 35 years long term historical data collected from the national meteorological agency of Ethiopia, and Kulumsa and Debre Zeit agricultural research centers. The future climate data is downscaled using the output of ensemble of seventeen climate models under RCP4.5 and RCP8.5 scenarios. It has been noted that, the onset of rainy season was highly variable compared to the cessation date. The Mann-Kendall trend test was showed an increasing trend of annual onset of rain in all study sites. Meaning that, late onset was perceived over the study period which in turn reduces the length of growing season (LGS) of the study area. The LGS for the study area was also highly variable, implying that difficulty in understanding the pattern of LGS in the area. The Mann–Kendall trend test shows a decreasing trend of cessation date, LGS and number of rainy days in all study sites. This indicates that, the LGS is reduced and this can in turn reduces the amount of rainfall received by the study area. On the other hand, under rain fed farming, the occurrence of the intermittent dry spells also becomes critical particularly for seedling and tillering stages during the first 30 days after planting. In fact, a dry spell of length of

5, 7 and 10 days could occur at some stage of crop growth; however, there is higher potential for damage when it coincides with the most sensitive stages such as flowering and grain filling. In the study area, the probability of dry spells of 5 days was found to occur even at the middle of rainy season but with risk less than 20%. This carries useful information for planting decisions by risk taking farmers who work under different capability or resource endowments.

Moreover, the annual and Belg rainfall amounts in the study area has been at a declining front in all study sites, despite the statistical test of the trends were found non-significant at Debre Zeit and Kulumsa areas. Although the trend is statistically none significant, Kiremt rainfall has increasing trend at Arsi Robe and Kulumsa while decreasing over Asasa and Debre Zeit areas. The total rainfall of shorter rainy season (Belg) and dry season (Bega) were highly variable compared to the main rainy season (Kiremt). The projected highest mean monthly rainfall during wheat growing season will be in July and the lowest rainfall will be in the month of October at all study sites. Generally, the magnitude and direction of seasonal rainfall was not uniform due to high inter-annual variability as compared to the annual rainfall. The highest projected mean monthly air temperature will be in the month of May while the lowest temperature will be in the month of November in all study sites. Beside to the seasonal and annual variability, the analysis of extreme temperature indices revealed that warm extremes are increasing while cold extremes decreasing in all study sites. These series clearly indicate significant warming and individual stations show most spatial coherence in all temperature indices while it is not the case for precipitation indices.

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