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Analysis of projected climate change in sorghum growing semi-arid rift valley of Ethiopia

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Abstract. Global warming projected to have a significant impact on agricultural water availability for crops in Africa in particularly in Ethiopia. Therefore, the study was conducted to analyze the projected change of temperature and rainfall in sorghum growing semi-arid rift valley of Ethiopia. The weather data for 11 stations were generated using AgiMP5 technique for RCP 4.5 and 8.5 and for the period of 2050s and 2080s. MAKESENS employed for the detection of trend of extreme indices. InStat v3.37 were used for the analysis of start, end, and length of growth season. Under RCP 4.5, the projected mean annual minimum air temperatures in CRV, ERVE and NRVE could increase respectively by 1.9 °C (2050s) and 2.6 °C (2080s), 1.8 °C (2050s) and 2.5 °C (2080s) and 1.88 °C (2050s) and 2.69 °C (2080s). Under RCP 8.5, however, with same location it will projected to increase in both time frames (2050s and 2080s) in all studied sites. The mean annual maximum air temperature, projected under RCP 4.5 in the CRV, ERV and NRVE will increase by 1.59 °C (2050s) and 2.18°C (2080s),1.42 °C (2050s) and 2.08 °C (2080s) and 1.46 °C (2050s) and 2.09 °C (2080s) respectively. However, under the RCP 8.5, at same regions it projected to rise in both periods (2050s and 2080s). This will be convoy with increase of the hot and cold extremes' indices in regions. The mean percentage change of annual rainfall is projected to decrease insignificantly in (0.6-5.5% and 2.6%) and increase (0.85-12.3% and 22.3%) in half of the stations located in CRV and ERVE, whereas, in NRVE it will projected to increase (6.1-14.6%) under RCP 4.5 in all stations in 2050s. Though the annual projected rainfall under RCP 4.5 in 2080s will decline in range of 2.1-10.1%, 3.12-4.5% and 0.9-4.6% at CRV, ERVE and NRVE respectively. In most of the location in CRV and ERVE stations growing season rainfall will projected to decline from 1.45% to 53.8% and 0.8 to 8.8%, whereas, in NRVE it will projected to increase in 9.2 to 19% under RCP 4.5 in period of 2050. The projected SOS will be changed in mixed pattern, whereas and LGP will prolonged in most locations. The findings indicated that there has been a change of projected climate change in semi-arid RV, which will be alter the agricultural practices in depletion of soil moisture. Therefore, in adjusting planting timing and using early/medium maturation sorghum varieties, may be necessary for farmers in the region. Soil and water management needs attention.

Keywords: climate change, air temperature and rainfall change, extreme indices, SOS, EOS and LGP.

1. INTRODUCTION

According to the United Nations Framework Convention on Climate Change (UNFCCC, 2017), developing nations are greatly susceptible to the consequences of climate change since they possess fewer resources to facilitate adaptation. Niang et al. (2014) and the Intergovernmental panel on Climate change (IPCC 2014, 2019) point out that Africa is among the continents that are significantly influenced by climate change and variability. In recent years, several global proceedings, such as the IPCC (2014) and the World Bank (2019), have raised concerns about the exacerbation of food security and economic insecurity. These concerns are particularly relevant in Sub-Saharan Africa (SSA), which has the highest prevalence of undernourishment according to Sonwa et al. (2017), OECD/FAO (2016). Furthermore, key economic sectors in SSA are highly vulnerable to climate change and variability, as depicted in various studies, including Mahoo et al. (2013), Ceci et al. (2021), and Sonwa et al. (2017). The resulting economic consequences have been significant as reported by Sonwa et al. (2017) and the OECD and FAO (2016). Sub-Saharan Africa (SSA) is a key concern in region food security (FAO, 2011). Within the SSA region, Eastern Africa and Ethiopia, in particular, are identified as being the most vulnerable to climate inconsistency and change by USAID (2015) and NAP (2019). This vulnerability is due to the region's reliance on rain-based agriculture (Schlenker and Lobell, 2010; IMF, 2020; World Bank, 2019). Additionally, the relatively limited capacity of the region to absorb shocks further exacerbates the situation (Schlenker and Lobell, 2010; World Bank, 2019). In the coming fifty years and subsequent periods, it is projected that climate change will significantly affect the agricultural sector of Ethiopia and its overall societal progress (Arndt et al., 2011; Thomas et al., 2019), highlighting the urgent need for proactive measures to address this concern.

According to various scholarly sources, it has been projected that during the 21st century, the rate of temperature increase in Africa will exceed the global average (Joshi et al., 2011; Sanderson et al., 2011; James and Washington, 2013). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), Africa has experienced an excessively substantial influence from climate change compared to other continents. The continent is poised to face significant vulnerability arising from its geographical location, characterized by a notably diminished adaptive capacity that is further compounded by the prevalence of poverty and a preexisting shortage of development (IPCC, 2007). Due to climate change the East African region, specifically Ethiopia, is projected to experience a rise in temperatures with increase by 1.8 °C in the mid-century and 3.7 °C in the end-century, as reported by the IPCC (2019), Irish Aid (2018), and the CCKP (2020). Various climate models produce only slightly varying projections for temperature increase while presenting differing anticipations for changes in rainfal patterns. The accuracy of Ethiopia's projected rainfall remains uncertain. Nevertheless, projection suggest a marginal increase in the country's cumulative rainfal (USAID, 2015; IPCC, 2019; CCKP, 2020). The high-emission scenarios: projected to result in a relatively low mean annual rainfall rate, which increase significantly by the end of the century (CCKP, 2020).

The phenomenon of climate change has already had a significant adverse impact on various aspects of people's livelihoods, with projected future exacerbations as posited by the IPCC, (2019). According to Mahoo et al. (2013), there is a significant susceptibility of Ethiopia's economy to the impacts of climate change and variability. The projected posits that by the year 2050, the gross domestic product (GDP) of Ethiopia may experience a decline ranging from 8% to 10%. (CIAT; BFS/USAID, 2017; World Bank, 2021) This decline is mainly attributable to the impact of climate change on agricultural productivity, with drought serving as a major contributing factor (CIAT; BFS/USAID, 2017). The nation's gross domestic product (GDP) has been negatively impacted by up to 4% as a result of recent severe droughts (USAID, 2016) Furthermore, it has been projected that rain-induced soil erosion may lead to an additional decrease in GDP by approximately 1% (CGIAR, 2018). However, the financial consequences of these environmental factors are primarily contingent on the levels of rainfall received annually, as well as the variations and extremes of temperature (CGIAR, 2018).

Furthermore, global warming is projected to have a significant impact on agriculture water availability in Africa.in particularly in Ethiopia Agriculture. The literature suggests that there will be a reduction in growing periods and an increase in water stress in many parts of the continent (World Bank, 2021). Specifically, studies have shown that the expected warming patterns in Ethiopia may exacerbate current rainfall deficits, leading to elevated levels of water scarcity (MoFE, 2015; USAID, 2016). Moreover, research indicates that there exists a negative correlation between annual rainfall and the productivity of important crops such as millet, sorghum, and maize in the northern region of Ghana (Ndamani and Watanabe, 2015). Additionally, there is evidence that rising temperatures, coupled with an increase in the frequency and intensity of droughts, have had a significant impact on Ethiopia's grain yield (WFP, 2014; USAID, 2015; World Bank, 2019). According to Shanahan et al. (2013), it is anticipated that there will be an increase in flooding and extreme rainfall, causing substantial detrimental impacts on Ethiopian production output and environmental conditions. Low temperature extremes are a critical determinant of the pace of plant growth and development, and the distribution of plant genotypes in diverse geographic localities across the globe (Ramankutty et al., 2008; Yadav, 2009). The research conducted by Maulana and Tesso (2013) indicates that the impact of cold extremes on the growth rate and duration of flowering of sorghum plants differs across various genotypes in the semi-arid region of Ethiopia.

Rainfed cereal production and limited livestock rearing support households in semi-arid Rift valley. High rainfall variability and drought cause crop failure and famine in the central rift valley (Kassie et al., 2013; Getent and Alister, 2012). The region is a significant land portion of the country that is environmentally vulnerable to climate change (Kassie et al., 2013; Hadgu et al., 2013; Muluneh, 2017). In order to develop effective climate change adaptation strategies for agricultural systems, an investigation into both the variability and predictability of forthcoming rainfall and air temperature changes is imperative (Thornton et al., 2009; Kassie et al., 2013). The task of monitoring changes in regional climate is vital for exploiting agricultural advancements that could potentially heighten productivity, while concurrently steering clear of circumstances that may give rise to substantial stress (Thornton et al., 2009). The ability to accurately climate change projection patterns is largely contingent upon the availability of regional climatological data, as highlighted in previous research conducted by Oates et al. (2011). According to Ghosh and Mujumdar (2008), Global Circulation Models (GCMs) represent the most accurate means of modeling the response of the global climate system presently available. According to the Intergovernmental Panel on Climate Change's (IPCC, 2007), General Circulation Models (GCMs) are capable of providing estimates for alterations in multiple meteorological factors at grid cells typically measuring 250 km in width and 600 km in length. Consequently, the resolution they achieve is somewhat coarse. However, the results produced by General Circulation Models (GCMs) are seldom in a format that is applicable to a regional level, and substantial analysis is required prior to practical usage, to assess potential effects and suitable adaptation approaches (Jones and Thornton, 2013). The attainment of enhanced spatial resolution can be accomplished by down-sampling the outputs generated by coarse-scaled global climate models (GCMs). The climate impact community mostly accepted these methodologies that demonstrate empirical correlations between the output (predictors) of coarse-scale GCMs and local or station scale predictands (rainfall and/or) (Fowler et al., 2007; Green et al., 2011). Research on the implications of future climate change for agricultural production in the semi-arid rift valley of Ethiopia is currently is not enough or even lacking in most sorghum producing areas. Despite the importance of obtaining locally-relevant information on future climate patterns to develop effective adaptation strategies, no more as such studies have been conducted in this region. Therefore, the purpose of this study was to characterize and analyze the rainfall and air temperature outputs at a local scale, derived from selected GCMs climate change scenarios in the semi-arid rift valley of Ethiopia's sorghum producing region. Noteworthy, rainfed crop production in this area has experienced substantial growth in recent years (Jansen et al., 2007).

2. MATERIALS AND METHODS

2.1. Description of the study areas

The prominent geological feature of the Main Rift Valley in Ethiopia is characterized by its intricate terrain, which is marked by noteworthy tectonic escarpments that demarcate the rift floor from the adjacent plateaus. According to Corti (2013), this area is situated between the topographical elevations of the Ethiopian and Somali Plateaus. According to Keir et al. (2005) and Agostini et al. (2010), it is presently postulated that the faults situated in the northern Rift valley escarpment are in a state of quiescence. However, in the southern region, they are expected to remain tectonically and seismically active. The Ethiopian highlands are a notable geographical feature, resulting from the formation of the Main Rift Valley on either flank, as observed by Agostini et al. (2010).

This study focuses on the semi-arid rift valley of Ethiopia, which is located from 38°.07'–41°.11'E and 7°.85'-12°.42'N. It includes the heart and corridor of the Ethiopian Rift Valley, and encompasses semi-arid lowlands in the northwest and eastern areas. The CRV has a central valley floor at 1500-1700 m a.s.l. and is flanked by northern, western, and eastern escarpments exceeding 4000 m a.s.l. (Jansen et al., 2007). The CRV has a weak bi-modal rainfall pattern, typical for the central, eastern, and northern parts of Ethiopia. Valley floor gets 175-358 mm rain in the short season (Mar-May) and 420-680 mm in the main season (Jun-Sep). Eastern and northern rift valleys escarpments get 833 mm in the main season and 603 mm in the short season annually.

Andosol (orthic) is the most dominant soil, followed by phaeozems (ortic) and chromic luvisols (orthic) (FAO, 1984), due to the prevalence of silt and ash (white, volcanic) with high-water infiltration capacity. Due to agriculture and dense population, the flora is scarce, causing soil erosion in sloping areas with andosols.

Cereals, including teff, maize, sorghum, common beans, and wheat are the main crops. Past rainfall was analyzed for eleven stations in the CRV floor and its semi-arid escapements. Studied areas: CRV floor (Adami Tullu, Melkassa, Dhera, Matahara, Mieso, Melka Werer), Easter RV escapement (Abomsa, Gololcha), and northern RV escapement (Kobo, Sirinka, Alamata). All known for sorghum production and similar weather.

2.2. Historical meteorological data and future climate scenarios analysis

National Meteorology Agency Service (NMAS) provided historical daily rainfall, maximum and minimum air temperature data for different locations across the study region from 1989 to 2019. These climate data were used as baseline data to prepare local future climate scenarios. The site-specific future climate change scenarios were generated following the Agricultural Model Inter comparison and Improvement Project (AgMIP) technique, which uses the delta statistics approach (Hudson and Ruane, 2015). Downscaled future climate data as shown in Table 1 derived from five ensemble representative GCMs, namely, CSIRO-Mk3.6.0, HadGEM2-ES, IPSL.CM5A-MR, MIROC5 and MRI.GCM3 were selected out of the 20 GCMs that are available in the AgMIP climate scenario (Hudson and Ruane, 2015; Rosenzweig et al., 2015) ensembled for two RCP's (RCP 4.5 and RCP 8.5) and two time periods; 2050s (2040-2069) and 2080s (2070-2099) including the baseline scenario (1989-2019). These five GCMs were selected due to their long history of development and evaluation, a preference for higher resolution, and established performance in monsoon regions (Rosenzweig et al., 2013b).

The name of the global circulation models (GCM's) used for this study and their institutions is presented in Table 1. The projected future scenario data applied to analysis and characterize the future climate change in sorghum growing semi-arid Rift Valley under the medium (4.5 W/m^2) and maximum (8.5 W/m^2) irradiance energy striking the earth. RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models have produced corresponding emission scenarios (IPCC, 2013). The RCP 8.5 is a high emission scenario, corresponding to projections of high human population (12 billion by 2100), high rates of urbanization, and limited rates of technological change, all resulting in emissions approaching 30 Gt of carbon by 2100 compared with 8Gt in 2000 (Riahi et al., 2007). The RCP 4.5 scenario is an intermediate mitigation scenario characterized by a continuously increasing human population, but at a rate lower than in the RCP 8.5 scenario, intermediate levels of economic development and less rapid and more diverse technological change (Moss et al., 2010).

The projected changes of air temperature were calculated absolute difference (eq. 1) and the rainfall relative change of percentage(eq. 2), respectively.

$$\Delta T = Tmp - Tmb \tag{1}$$

$$RF\% = \frac{RFp-RFb}{RFb} * 100 \tag{2}$$

where ΔT is the absolute change of temperature, Tmp = projected temperature and Tmb baseline temperature and RF% = relative change of percentage of rainfall, RFp = projected rainfall, and RFb is baseline rainfall.

2.3. Data quality check and analysis of indices

Data quality control is essential for reliable indices. The data displayed for visual inspection and the detection of outliers to prevent potential issues that could affect the seasonal cycle (Abbas et al., 2013). The Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) of the Climate Research Branch of the Meteorological Service of Canada created the data and the technique in the RClimDex 1.3 program was used to further quality check the data. Its key function is to detect processing errors, including manual data entry mistakes. An assessment was done on daily air temperatures, and any values outside the user's range are considered outliers. Zhang et al. (2005) defined the findings within the range of the climatological mean value and four standard deviation (SD). The daily temperature was manually assessed and edited if it deviated from the prescribed range. RClimDex (1.3) computes 27 indices for extreme weather conditions in temperature and rainfall. ETCCDMI defined 27 core indices that include the most R.ClimDex (V.1.3) indices. In the study, 8 temperature indices and 10 rainfall indices were analyzed (Table 2).

2.4. Analysis of rainfall and air temperature indices trends

Non-parametric technique in Excel, the Mann-Kendall and Sen's (MAKESEN) slope estimator test utilized to find trends in the climate variables caused by climate

Table 1. Coupled Model Inter-comparison Project phase 5 (CMIP5) and general circulation models (GCM's) were used for this study.

No.	Institution	Model Name	Resolution		Reference	Country
			Lat	Long		
1	Commonwealth Scientific and Industrial Research Organization and the Queensland Climate Change Centre of Excellence	CSIRO-Mk3. 6-0	1.875	1.875	Collier et al. (2011)	Australia
2	Met Office Hadley Centre	HadGEM2-ES	1.75	1.25	Collins et al. (2011).	UK
3	Institute Pierre-Simon Laplace	IPSL CM5A-MR	1,2587	2.5	Dufresne et al. (2013).	France
4	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC5	1.4063	1.4063	Watanabe et al. (2010).	Japan
5	Meteorological Research Institute	MRI-GCM3	1.12	1.12	Yukimoto (2012).	Japan

Source: (IPCC, 2013).

Table 2. Temperature and rainfall indices used in the analysis.

s/n	Index	Index name	Definition of the index	Unit
Temperature indices				
1	TXx	Hottest day	Max Tmax: monthly maximum value of daily maximum temperature	°C
2	TNx	Hottest night	Max Tmin: monthly maximum value of daily minimum temperature	°C
3	TXn	Coolest day	Min Tmax: monthly minimum value of daily maximum temperature	°C
4	TNn	Coolest night	Min Tmin: monthly minimum value of daily minimum temperature	°C
5	TN10p	Cool night frequency	Percentage of days when TN <10th percentile of the baseline period	Days
6	TX10p	Cool day frequency	Percentage of days when TX <10th percentile of the baseline period	Days
7	TX90p	Hot day frequency	Percentage of days when TX >90th percentile of the baseline period	Days
8	TN90P	Hot night frequency	Percentage of days when TN >90th percentile of the baseline period	Days
Rainfall Indices				
1	RX1da y	Max 1-day rainfall amount	Monthly maximum 1-day rainfall	mm
2	Rx5day	Max 5-day rainfall amount	Monthly maximum consecutive 5-day rainfall	mm
3	R10	Number of heavy rainfall days	Annual count of days with rainfall ≥10 mm	Days
4	R20	Number of very heavy rainfal days	Annual count of days with rainfall ≥20 mm	Days
5	CDD	Consecutive dry days	Maximum number of consecutive days with rainfall <1 mm	Days
6	CWD	Consecutive wet days	Maximum number of consecutive days with rainfall ≥1 mm	Days
7	PRCPTOT	Annual total wet-day rainfal	Annual total rainfall from days ≥1 mm	mm
8	SDII	Simple daily intensity index	Simple rainfal intensity index	mm/day
9	R95P	Very wet days	Annual total rainfal when RR>95 percentile	mm
10	R99P	Extremely wet days	Annual total rainfal when RR>99 percentile	mm

change, (Timo et al., 2002). According to Da Silva et al (2015), the main benefits of non-parametric methods include the ability to use datasets with missing values and the fact that the data need not follow a specific distribution and to identify whether there is a positive or negative trend based on statistical significance (Amadi et al., 2014).

A non-parametric method called the Mann-Kendall (MK) test is frequently used in different trend identification research (Karaburun et al., 2011). Given the possibility of ties (i.e., equal values) in the x values, the variance of S is as below:

$$var(S) = 1/18\left|N(N\text{-}1)(2N+5)\text{-}\Sigma^{M}_{i=1}ti(ti\text{-}1)(2ti+5)\right| \qquad (3)$$

where: M is the number of tied groups in the data set and *ti*is the number of data points in the *ith* tied group. For n larger than 10, *ZMK* approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun et al., 2008) and computed as follows:

for n larger than 10, the standard normal Z test statistic used and computed from eq. 8 as

$$Z = \begin{cases} \frac{s-1}{\sqrt{var(s)}} & ifs > 0 \\ & ifs = 0 \\ \frac{s+1}{\sqrt{var(s)}} & ifs < 0 \end{cases} \tag{4}$$

The presence of a statistically significant trend was evaluated using the Z value. A positive or negative value of Z indicates an upward or downward trend. The statistic Z has a normal distribution. In a two-sided test for trend, the null hypothesis Ho should accept if $|ZMK|<Z1-\alpha2$ at a given level of significance. $Z1-\alpha2$ is the critical value of ZMK from the standard normal table. e.g., for 5% significance level, the value of $Z1-\alpha2$ is 1.96…

The Sen's estimator of slope; to estimate the true slope or magnitude of an existing trend (as change per year). The Sen's method can be used in cases where the trend can assume to be linear. This method could be used with missing data and remain unaffected by outliers or gross errors (Karpouzos et a*l.,* 2010). Then, the slope magnitude (change per unit time) was estimated for both rainfall and temperature:

$$Q = Q_{\frac{N+1}{2}} \quad \text{if } N \text{ is odd number} \tag{5}$$

$$Q = \frac{1}{2}(Q_{\left(\frac{N}{2}\right)} + Q_{\left\{\frac{N+2}{2}\right]}) \quad \text{if } N \text{ is even} \tag{6}$$

2.5 Determination of the start, end, and length of growing period

Various authors use different threshold values to determine the start (SOS) and the end of the growing season (EOS). The criteria used in this study were a rainfall of 20 mm or more accumulated over three consecutive rainy days after a specified date (in this case June first) with no dry spell greater than 9 days in the next 21 days (Girma, 2005; Liben, 2013; Edao et al., 2018). SOS is calculated as (eq. 7):

$$\boldsymbol{SOS = D\,\frac{(20-F)}{R}} \tag{7}$$

where; D is the total number of days in the first month with effective rain (MER: accumulated rainfall totals equal or exceeds 20 mm). F (mm) is the accumulated rainfall total of earlier months and R is the accumulated rainfall within the MER.

Moreover, the end of the season (EOS), was defined as the date when the available soil water content dropped to 10 mm m^{-1} of available water (Dodd and Jollite, 2001; Tesfaye and Walker, 2004; Girma, 2005; Liben, 2013; Edao et al., 2018) in October. Rainfall end dates were also calculated using (eq. 8):

$$\boldsymbol{EOS = b + 275} \tag{8}$$

where EOS is any day from 1st October after which there are more than 7 consecutive days of rainfall amounts below 50% of the soil water requirement and "b" denotes the number of days in which there is maximum build-up of pre-season moisture.

The Length of the growing period (LGP): is a key factor in deciding on the maturity of cultivars to be grown in dissimilar rainfall regimes. Therefore, LGP is considered as the period from the SOS to the EOS. (eq 9)

$$LGP = EOS - SOS + 1 \tag{9}$$

3. RESULTS AND DISCUSSIONS

3.1. Projected change of air temperature in the semi-arid rift valley

3.1.1. Projected change of maximum and minimum air temperature

The findings of this study reveal that the projected future mean annual minimum and maximum air temperatures across several locations in the semi-arid Rift Valley will increase under both RCP scenarios (4.5 and 8.5) and time frames (2050s and 2080s) based on an ensemble of five General Circulation Models (GCMs) namely CSIRO-Mk3.6.0, HadGEM2-ES, IPSL CM5A-MR, MIROC5, and MRI-GCM3 (Table 3). Only in Melka Werer there is no value in 2080 for the mean annual maximum air temperature due to high uncertainty in period of RCP 8.5, while the other studied areas will experience an increase in air temperature. Furthermore, the study indicates that the average increase in minimum air temperature in the CRV region could potentially reach 1.91 °C and 2.56 °C under the RCP 4.5 scenario in 2050s and 2080s and under the RCP 8.5 in the year 2050s and 2080s and 2.61 °C and 4.82 °C respectively (Table 3). For RCP 4.5, the mean of the projected minimum air temperature increase in the Eastern(ERVE) and Northern Rift Valley Escapements(NRVE) is 1.8°C and 2.57 °C, and 1.88 °C and 2.66 °C by mid-century and end of century respectively. The projected increase for the RCP 8.5 in the mid and end of the century are much higher, up to 2.53 and 4.76 °C and 2.67 and 4.88 °C, respectively (Table 3).

Based on the findings stated earlier, the minimum air temperature is projected to be higher in the NRVE followed by CRV then ERVE in both analyzed periods and scenarios (Table 3). The end of the century, the minimum air temperature in both scenarios will be

Table 3. Projected change of annual air temperature in CRV, floor, ERVE, and NRVE of Ethiopia in 2050s and 2080s using five GCM models for RCP 4.5 and RCP 8.5 scenarios.

Locations /Sites LSites		Minimum Temperature change				Maximum Temperature change				Mean Temperature change			
		2050		2080		2050		2080		2050		2080	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
CRV	AdamiTullu	1.66	2	2	3.65	1.46	2.33	2.34	4.36	1.56	2.17	2.17	4
	Melkassa	1.84	2.61	2.55	4.91	1.43	2	2.05	3.61	1.63	2.3	2.3	4.26
	Dhera	1.83	2.60	2.54	4.91	1.43	2	2.05	3.61	1.63	2.3	2.29	4.26
	Abomsa	2.28	3.06	2.89	5.36	1.88	2.45	2.3	4.03	2.8	3.75	2.54	4.69
	Matahara	1.95	2.75	2.68	5.03	1.94	2.10	2.17	3.68	1.94	2.42	2.43	4.35
	Melka Werer	1,90	2.67	2.72	5.03	1.44	2.08	2.19	-	1.67	2.36	2.46	3.59
	mean	1.91	2.61	2.56	4.82	1.59	2.16	2.18	3.85	1.87	2.55	2.37	4.19
ERVE	Mieso	1.78	2.46	2.6	4.78	1.42	2.09	2.03	3.61	1.6	2.32	2.27	4.19
	Gololcha	1.82	2.59	2.54	4.74	1.41	2.04	2.06	3.28	1.62	2.32	2.3	4.01
	mean	1.8	2.53	2.57	4.76	1.42	2.07	2.05	3.45	1.62	2.32	2.29	4.1
NRVE	Kobo	1.9	2.8	2.7	4.9	1.9	2.1	2.0	3.8	1.7	3.85	2.45	4.4
	Sirinka	1.77	2.55	2.45	4.77	1.44	2.05	2.12	3.67	1.605	2.3	2.285	4.22
	Alamata	1.97	2.65	2.84	4.97	1.44	2.1	2.07	3.81	1.71	2.38	2.46	4.39
	mean	1.88	2.67	2.66	4.88	1.46	2.08	2.09	3.76	2.51	2.84	2.39	4.34

CRV=central rift valley, ERVE=eastern rift valley escapement, NRVE= northern rift valley escapement.

warmer compared to the mid-century. Within the studied three locations, the highest change in minimum air temperature is projected in Abomsa and the lowest will be encountered in Adami Tullu across all stations examined, in both time frames (2050s and 2080s) and scenarios (4.5 and 8.5) (Table 3). Table 3 reveals that both emission scenarios (4.5 and 8.5) exhibit a trend of 2080s minimum air temperatures will be warmer compared to baseline period (1989-2019) during the mid-century across all stations examined. Specifically, the RCP 4.5 displays this pattern at all analyzed stations.

For the RCP 4.5, the projected mean change in the maximum air temperature of the CRV floor is projected to rise in 1.59 and 2.18 °C for the periods of 2050s and 2080s, respectively (Table 3). Similarly, for the RCP 4.5, it found that the mean change of the projected maximum air temperature rise in the ERVE and NRVE will be 1.42 and 2.08 °C and 1.46 and 2.09 °C, respectively, for the periods of 2050s and 2080s. Furthermore, in the RCP 8.5 the projected changes in the maximum air temperature will be identified as increasing by 2.16 and 3.85 °C in the CRV floor, 2.04 and 3.45 °C at ERVE, and 2.08 and 3.76 °C in the NRVE during the periods of 2050s and 2080s, respectively (Table 3). The analysis indicated that the projected maximum air temperature towards 2080s will be warmer than 2050s expected for CRV during 2080s and less warm than in 2050s (Table 3). The CRV will experience higher air temperatures under the RCP 4.5 in both 2050s and 2080s compared to the ERVE and NRVE areas. Additionally, during the 2050s period, the CRV will be even warmer compared to the baseline period (1989-2019), in contrast to the ERVE and NRVE areas for the RCP 8.5.

In the coming decades, specifically during the 2050s and 2080s, it is projected that the mean air temperature in the CRV, ERVE and NRVE areas will rise significantly in both emission scenarios (4.5 and 8.5). The projected mean air temperature increase will be around 1.85 °C, 1.62 °C, and 2.52 °C for the RCP 4.5, and around 2.55 °C, 2.33 °C, and 2.84 °C for the RCP 8.5 during 2050s respectively in CRV, ERVE and NRVE. Towards the end of the century, there is an expected rise in the mean air temperature in the CRV, ERVE, and NRVE areas to be around 2.37 °C, 2.29, and 2.39 °C for the RCP 4.5, and around 4.19, 4.1 and 4.34 °C for the RCP 8.5, respectively (Table 3).This confirms IPCC's (2014) postulation that the average temperature will increase by 2-3 °C by the mid-century and by 4-6 °C by the end of the 21st century over East Africa including Ethiopia. The projected future temperature increase was also shown by Gebrechorkos et al. (2023), Weldegebriel and Prowse (2013) for East Africa, by World Bank (2022) particularly in Ethiopia, by Adem and Abebe (2022) in Northern Ethiopia, by Teshoma (2022) in Eastern Ethiopia, and by Kassie et al. (2013) in CRV.

The change in the projected future mean air temperature is more dramatic in minimum air temperature than in maximum air temperature, and the magnitude of the change depends on location, emission scenarios, and time frames. The results of the analysis suggest that, at RCP 4.5, CRV is projected to exhibit higher air temperatures than two other regions, namely, ERVE and NRVE, in 2050s. However, under RCP 8.5, NRVE is expected to experience greater levels of warmth during 2080s than 2050s. The current findings are consistent with publications by IPCC (2013) and Gebrechorkos et al. (2023) for east Africa, and Kassie et al. (2013) for the CRV, in which the expected future shift in minimum air temperature is higher than maximum air temperature. According to Halfield et al. (2011) report, the projected increase in air temperature may result in a reduction in yield by an estimated ranging between 2.5% to 10% across several crop species. Abera's (2022) conflicting findings suggest that a 1% increase in mean air temperature during the crop's growth phase results in a proportional yield increase of 2.4% in the sorghum crop.

3.1.2. Projected change in seasonal mean air temperature

The projected main rainy season mean air temperature experience an increase pattern across all examined regions. Specifically, there will be an increase by 1.65 °C, 1.56 °C, and 1.69 °C in the 2050s for the CRV, ERVE and NRVE, respectively. Furthermore, in the 2080s, it is expected that there will be a change in mean air temperature, with an increase by 2.29 °C, 2.26 °C and 2.42 °C under RCP 4.5 for the same areas (Table 4). For the RCP 8.5, it is projected that the future mean air temperature during the main rainy season will increase by 2.36, 2.28, and 2.42 °C for the 2050s, and by 4.18, 3.87, and 4.38 °C for the 2080s, respectively in the CRV, ERVE and NRVE (Table 4). The findings have demonstrated that, during the main growing season, the projected mean air temperature in the NRVE will be warmer than both areas, with the CRV following in subsequent order. As shows in Table 4 that the short rainy season projected future mean air temperature is to be increase in the range of 1.74 °C (CRV)-1.61 °C (ERVE) in 2050s and 2.38 °C (ERVE)-2.45 °C (NRVE) in 2080s for the RCP 4.5. By the 2050s and 2080s respectively, the projected future short rainy season mean air temperature will be expected to rise by 2.35 °C (ERVE)-2.43 °C (CRV) and 4.31 °C (NRVE)-4.35 °C (CRV) for the RCP 8.5 (Table 4). The projected dry season mean air temperature in the semi-arid rift valley locations is expected to rise in range of between 1.63 °C (NRVE) and 1.77 °C (CRV) in 2050s and during 2080s it will rise in range of 2.23 °C (ERVE)-2.37 °C (NRVE) for the RCP 4.5. The dry season projected mean air temperature rise will be expected in range of 2. 44 °C (ERVE) to 2.52 °C (CRV) by the 2050s and increase range of 4.26 °C (ERVE) to 5.55 °C (CRV) in 2080s for the RCP 8.5 (Table 4). As showed in Table 4, due to high uncertainty there is no value of the Melka Werer site located in CRV for the main rainy season, short rainy season and dry season.

During 2050s in CRV floor and ERVE, the mean seasonal air temperature will increase consistently from main rainy season to dry season in both RCP 4.5 and 8.5,

Table 4. Projected future mean air temperature (°C) change for the main rainy, short rainy, and dry season as compared to baseline period (1989-2019) under RCP 4.5 and RCP 8.5 scenarios in CRV floor, ERVE and NRVE of Ethiopia

Time Slices	Scenario	Season	CRV							ERVE			NRVE			
			Adami Tullu	Melkassa	Dhera	Abomsa	Matahara	Melka Werer	Mean	Miesso	Gololcha	Mean	Kobo	Sirinka	Alamata	Mean
2050	RCP 4.5	MRS	1.57	1.53	1.52	1.99	1.65	1.65	1.65	1.56	1.56	1.56	1.73	1.61	1.74	1.69
		SRS	1.52	1.66	1.65	2.137	1.79	1.71	1.74	1.57	1.65	1.61	1.71	1.55	1.73	1.66
		DS	1.6	1.71	1.71	2.135	1.81	1.65	1.77	1.67	1.67	1.67	1.66	1.59	1.65	1.63
	RCP 8.5	MRS	2.2	2.18	2.17	2.64	2.29	2.26	2.29	2.22	2.21	2.22	2.56	2.27	2.39	2.41
		SRS	2.24	2.33	2.31	2.79	2.46	2.42	2.43	2.34	2.35	2.35	2.41	2.32	2.49	2.41
		DS	2.2	2.42	2.42	2.85	2.87	2.41	2.52	2.47	2.41	2.44	2.57	2.34	2.34	2.46
2080	RCP 4.5	MRS	2.2	2.28	2.27	2.56	2.39	2.47	2.36	2.26	2.29	2.28	2.44	2.34	2.48	2.42
		SRS	2.23	2.36	2.35	2.68	2.49	2.54	2.44	2.38	2.38	2.38	2.52	2.31	2.51	2.45
		DS	2.12	2.28	2.28	2.57	2.39	2.38	2.34	2.21	2.25	2.23	2.42	2.29	2.40	2.37
	RCP 8.5	MRS	4.06	4.1	4.07	4.50	4.16	-	4.18	3.98	3.75	3.87	4.43	4.25	4.48	4.38
		SRS	3.92	4.3	4.31	4.79	4.45	-	4.35	4.32	4.1	4.21	4.4	4.18	4.36	4.31
		DS	4.06	4.41	4.41	4.82	4.48	-	5.55	4.31	4.21	4.26	0.55	4.22	4.35	3.04

CRV=central rift valley, ERVE=eastern rift valley escapement, NRVE= northern rift valley escapement, MRS=main rainy season, SRS=short rainy season, DS=dry season but in NRVE there will be consistently increasing season mean air temperature from dry season to main rainy season in RCP 4.5. This indicated that in CRV and ERVE the dry season will warmer followed by the short rainy season, but in NRVE the main rainy season will warmer followed by the short rainy season. During the 2080s in CRV of Ethiopia, the dry season will warmer followed by the short rainy season, in RCP 8.5, whereas, in RCP 4.5 the short rainy season warmer than all followed by main rainy season .However, the short rainy season air temperature will warmer in ERVE and NRVE for RCP 4.5, but in 2080s for ERVE dry season and NRVE main rainy season will rapid warmer followed by a short rainy season for RCP 8.5 (Table 4). The report of Kassie et al. (2013) the seasonal projected future temperature in the CRV expected to increase, and Hadgu et al. (2013) and Adame and Abebe (2022) also reported that the seasonal air temperature in the northern expected to rise. This result reveals that growing season air temperature during crop growing season leads to aggravated evaporations and resulting in moisture stress suffered crops (Segele and Lamb, 2005). The ensembled climate models indicate that in the future the semi-arid rift valley of Ethiopia might be one of the most affected areas due to climate change and variability, with a simulated mean seasonal air temperature increase up to 4.82 °C in the mid and end century during the main rainy season compared to baseline (1989-2019) (Table 4). This finding corroborated by the finding of Mathur and Jajoo (2014), who noted that high air temperatures have an adverse impact on a variety of cellular processes involved in plant performance, which is directly linked to a decline in photosynthetic productivity and, ultimately, crop output. The use of long-duration cultivars is replaced by short-maturation ones, which have reduced yield potential, because of a rise in temperature (Wylie, 2008).

3.1.3. Projected extreme air temperature trend analysis in sorghum growing areas

Hot extremes. As indicated in Table 5, the trend analysis of the hottest day (TXx) and night (TNx) of the projected future maximum and minimum temperatures and their frequencies (TX90p and TN90p) will increase in the 2050s and 2080s under RCP 4.5 and 8.5 scenarios at Melkassa (CRV) and Mieso (ERVE) stations. However, the trend of the projected future TXx will decrease non significantly but the TNx and TX90P and TN90P will increase under RCP 4.5 and 8.5 during mid and end century at Kobo (NRVE) (Table 5). The TXx are projected to increase more than TNx at Melkassa and TNx are projected to increase than TXx at Mieso site. Other disagreeing reports found the projected future hot day and night frequency will be expected to decrease in the mid and end century in Ethiopia (McSweeney et al., 2008).

The projected future TNx will expect to increase more rapidly than the TXx over Melkassa and Mieso, whereas in the Kobo region the projected TXx to increase more than the TNx (Table 5). Consistent with the findings of this study, Omondi et al (2014), Dosio et al. (2018), and Kharin et al. (2018) indicated increasing trends in TXx and TNx over east Africa. This implies that extreme temperature rises as well as the increase in the frequency and intensity of droughts and floods are likely to reduce crop yields (World Bank, 2020). In Ethiopia, the projected future TXx and TNx are likely to increase, which will mostly affect the arid and semi-arid and pastoral areas in the country (McSweeney et al., 2008; Murken et al., 2020).

Cold extremes. The present study reveals that the analysis of the cool temperature metrics, namely, the coolest day (TXn) and coolest night (TNn), indicates an upward trend across the selected regions under two RCP, namely 4.5 and 8.5, during the 2050s and 2080s. However, it is noteworthy that the projected TNn will expected to show a non-significant decrease exclusively in the Kobbo region (Table 5). In contrast to Mieso region where the projected frequency of the coolest day (TX10P) does not exhibit a statistically significant decline, it is observed that both Melkassa and Kobo regions experience a notable decrease in the TX10P (Table 5). According to the findings, the projected frequency of the coolest night (TN10P) exhibited a non-significant decrease across both the 2050s and 2080s, as well as the RCP 4.5 and 8.5, in the Melkassa area. Furthermore, a decrease will be observed in Mieso for the RCP 4.5 across both time frames (2050s and 2080s). The findings suggest that the TN10P in Kobo is expected to increase in RCP 4.5 and 8.5, as well as in 2050s and 2080s. Additionally, an increase in the occurrence of TN10P is predicted for Mieso under the RCP 8.5, encompassing the time frames of 2050s and 2080s (Table 5). Cold extremes are a key factor in the rate of plant growth and development, as well as the distribution of plant genotypes in various regions of the planet (Ramankutty et al., 2008; Yadav, 2009). The consequence of cold extremes on plant growth rate and days to flowering varies among sorghum genotypes (Maulana and Tesso, 2013).

3.2. Projected change of rainfall in semi-arid CRV

3.2.1. Changes in annual and seasonal rainfall

Annual total rainfall change. As indicated by Table 6, the average projected future mean annual rainfall

Table 5. Trends in air temperature indices in the baseline period (1989-2019) and in 2050s and 2080s for the selected three stations in CRV floor, ERVE, and NRVE of Ethiopia under RCP 4.5 and 8.5 scenarios.

Parameters	CRV floor					ERVE					NRVE				
	Melkassa					Miesso					Kobbo				
	baseline	RCP 4.5		RCP 8.5		RCP 4.5			RCP 8.5		baseline	RCP 4.5		RCP 8.5	
	2019	2050	2080	2050	2080	2019	2050	2080	2050	2080	2019	2050	2080	2050	2080
TXx	0.071	0.072	0.076	0.07	0.068	0.022	0.004	0.004	0.001	0.0012	0.035	-0.017	-0.013	0.05	-0.13
TNx	0.0095	0.022	0.028	0.026	0.033	0.053	0.057	0.053	0.056	0.053	0.036	0.03	0.031	0.03	0.033
TXn	0.067	0.071	0.067	0.067	0.065	0.066	0.058	0.063	0.067	0.068	0.065	0.15	0.14	0.15	0.14
TNn	-0.01	0.004	0.002	0.002	0.005	0.01	0.025	0.024	0.02	0.034	0.015	-0.025	-0.02	-0.008	-0.015
TN10P	-0.035	-0.05	-0.04	-0.04	-0.046	-0.39	-0.305	-0.32	0.305	0.31	0.19	0.11	0.13	0.11	0.125
TX10P	-0.26	-0.18	-0.19	-0.18	-0.19	-0.15	-0.11	-0.15	-0.11	-0.15	-0.41	-0.17	-0.19	-0.17	-0.19
TN90P	0.21	0.14	0.14	0.**15**	0.14	0.42	0.24	0.25	0.24	0.25	0.29	0.103	0.11	0.103	0.11
TX90P	0.31	0.23	0.23	0.23	0.23	0.18	0.11	0.12	0.12	0.12	0.65	0.23*	0.22*	0.22*	0.23*

Bolds figures indicates statistical significance at less than 5% alpha level.
CRV=central rift valley, ERVE=eastern rift valley escapement, NRVE= northern rift valley escapement.

output of five global circulation models (GCMs), namely, CSIRO-Mk3.6.0, HadGEM2-ES, IPSL-CM5AMR, MIROC5, and MRI -GCM3, suggests a mixed change in most of the stations located in the CRV floor and ERVE. The range of this decline is estimated to be between 0.6% (Dhera)-5.5% (Melka Werer) and 0.32% (Mieso) during the 2050s in the RCP 4.5, relative to the baseline period(1989-2019). Towards the 2080s, compared to the reference period of 1989-2019, it is projected that the annual average rainfall will decrease significantly in various regions. Specifically, the CRV floor, ERVE and NRVE are predicted to experience declines ranging from 0.67% (Melkassa)-10.1% (Melka Werer), 3.1% (Gololcha)-4.9% (Mieso), and 0.9% (Alamata)-4.6% (Sirinka) under RCP 4.5. The projected future annual rainfall as presented in Table 6, in some analyzed areas will be expected to rise in the range of 0.9 (Matahara)-12.3%(Abomsa), 22.3% (Golocha) and 6.1 (Alamata)-14.6% (Sirinka) respectively in the CRV, ERVE and NRVE during 2050s. In the other hands, the projected total annual rainfall will expected to be rise in NRVE in range of 6.1% (Alamata)-14.6% (Sirinka) during 2050s for the RCP 4.5.

The mid-century ensembles for mean annual rainfall in Ethiopia suggest significant uncertainty regarding both the magnitude and direction of changes across the models, particularly with respect to the RCP 4.5 (McSweeney et al., 2008; USAID, 2015). Various reports have offered distinct projections regarding the mean total rainfall in different regions of Ethiopia. For instance, some have suggested a decrease in north-east Ethiopia (MoFE, 2015), while others have predicted an increase in north Ethiopia (Adam and Abebe, 2022) and eastern Ethiopia (Teshoma et al., 2022). Meanwhile, other studies have observed a decrease in the CRV (Kassie et al., 2013) as well as northern Ethiopia (MoFE, 2015). In general, reported by McSweeney et al. (2008), different models projected in the ensemble are broadly consistent in indicating increases in annual rainfall in Ethiopia.

In a congruent manner, the RCP 8.5 projected for the 2050s and 2080s exhibits a discernible pattern of annual total rainfall increase across all examined locations (Table 6). In the context of a RCP 8.5 during the 2050s, the researched locations within the CRV, ERVE and NRVE will predicted to experience an annual increase in total rainfall within the ranges of 1.3-13.7%, 7.5%, and 16-18.4%, respectively (Table 6). Conversely, towards the 2080s under the same RCP 8.5, substantial increases in total rainfall will expected, with ranges of 9.3-40.9% for the CRV, 22.3% for the ERVE, and 31.3-32.5% for the NRVE (Table 6). This result is consistent with the reports of CCKP (2020), the annual mean rainfall slightly increases by the 2080s, under RCP 8.5 in Ethiopia and as reported by Nikulin et al. (2018) and Osima et al. (2018) the projected mean annual rainfall will be higher, particularly in the eastern parts of east Africa will expected.

Seasonal rainfall's change. As presented in Table 6, the ensemble output of the Global Circulation Models (GCMs) indicates a projected decrease in the future main rainy season rainfall. This reduction is expected to occur within the range of 1.45% to 53.8%, across more than 50% of locations in the CRV area. Only Mieso in ERVE exhibited such a decrease in 0.83% of rainy season rainfall. The

Table 6. Projected changes in percentage (%) of the annual and seasonal rainfall totals in CRV floor, ERVE, and NRVE of Ethiopia in 2050s and 2080s under RCP4.5 and 8.5 scenarios.

Rainfall	Time horizon	Scenarios	CRV floor						ERVE		NRVE		
			Adami Tullu	Melkassa	Dhera	Abomsa	Matahara	Melka Werer	Mieso	Gololcha	Kobbo	Sirinka	Almata
Annual	2050	RCP 4.5	-4.9	0.86	-0.6	12.3	0.9	-5.5	-0.32	22.3	10.2	14.6	6.1
		RCP 8.5	1.3	-3.5	7.9	24.4	13.7	5.04	-4.5	7.5	-2.4	18.4	16.6
	2080	RCP 4.5	-2.1	-0.67	-5.9	7.3	-2.3	-10.1	-4.9	-3.12	18.4	-4.6	-0.9
		RCP 8.5	9.3	-5	19.2	40.9	26.8	15.2	-55.6	22.3	32.5	31.3	32.4
Main Rainy Season	2050	RCP 4.5	-53.8	-1.45	0.62	9.1	-1.7	-8.8	-0.83	43.8	14.3	19.15	9.2
		RCP 8.5	-8.5	-8.01	7.9	16.2	6.6	-0.9	-13.2	0.8	-6.02	22.55	20.9
	2080	RCP 4.5	-10.4	-8.16	-6.14	0.6	-7.9	-15.05	-13.46	-10.8	23.9	-4.8	-4.35
		RCP 8.5	-7.2	-18.5	18.9	33.2	20.4	7.9	9.2	43.8	34.3	55.6	34.8
Short rainy season	2050	RCP 4.5	0.9	4.8	-5.1	3.1	2.5	-1.9	-0.12	28.8	10.3	4.35	3.6
		RCP 8.5	14.6	23.2	9.9	36.2	25.9	15.6	0.48	14.14	15.1	8.86	14.3
	2080	RCP 4.5	5.2	6.3	-3.6	16.6	6.2	-1.8	4.2	3.7	1.3	-1.3	0.43
		RCP 8.5	21.8	35.6	21.8	49.8	35.3	31.7	38.9	28.8	36.9	68	33.8

CRV=central rift valley, ERVE=eastern rift valley escapement, NRVE= northern rift valley escapement.

projected main rainy season in the CRV and ERVE will be more mixed change during mid-century in the RCP 4.5 (Table 6). However, in the NRVE, an increase ranging from 9.2% to 19.15% is expected during the 2050s in the RCP 4.5 compared to the base period. In contrast to the base period at the 2080s, it is projected that there will be a decrease in the amount of rainfall during the main rainy season across all examined regions under the RCP 4.5 expected Abomsa increase (Table 6). According to the projections based on the RCP 8.5, it is projected that the main rainy season will experience an increase of 6.6-16.2%, 0.8%, and 20.9-22.5% in the CRV floor, ERVE and NRVE, respectively, during 2050s, relative to the baseline period. In the present study, it found that an increase in the percentage of the main rainy season is expected during the 2080s. Specifically, the CRV floor, ERVE and NRVE will be expected to experience an increase in the range of 7.9-33.2%, 9.2-43.8%, and 34.3-55.6%, respectively, in comparison to the baseline period spanning from 1989 to 2019. Moreover, the mean result indicated a decrease in the projected future main rainy season for Melkassa and Adami Tullu, while an increase will be observed for Abomsa under both time frames (2050s and 2080s) and scenarios (4.5 and 8.5) (Table 6). The similar reports indicated that (Gutierrez et al., 2021; Otieno and Anyah, 2013; Kent et al., 2015) the projected future main rainy season mean rainfall will expected to increase under 2080s in east Africa.

Compared to the baseline period, it is projected that the mean short rainy season rainfall in the semi-arid Rift Valley of Ethiopia will experience a notable increase in the future.in both emission scenarios (4.5 and 8.5) and time frames (2050s and 2080s). However, it is projected that there will be a decline in rainfall in the locations of Dhera, Melka Werer, and Mieso by 2050s in RCP 4.5 and decrease at Dhera, Melka Werer and Sirinka by 2080s in RCP 4.5 (Table 6). This result was confirmed with the reports of Masilin et al. (2020), during the short rainy season, a longer rainfall projected over East Africa.

Regarding the local effects of climate variables, the significance of seasonal values is much more relevant than that of annual values. The projected mean seasonal rainfall will be expected to increase in the short rainy season than the main rainy season and more increase in NRVE than CRV and ERVE (Table 6). Current research suggests that an increase in rainfall is likely to give rise to a rise in crop productivity. Furthermore, it has been observed that crop productivity is notably more responsive to variations in rainfall compared to those in temperature (Kang et al., 2009). Moreover, it is crucial to employ moisture harvesting techniques to optimize crop production.in regions.

3.2.2. Projected future rainfall extremes trends

Maximum 1- and 5-days rainfall (R1xdays and R5xdays). The analysis of trends in the projected future maximum average rainfall for R1xdays and R5xdays, as presented in Table 7, reveals that there will be a discernible decrease at Melkassa and Kobo. Meanwhile, at Mieso, there will be a slight upward trend during the 2050s and 2080s periods under RCP 4.5. The analysis of projected future trends for R1xdays and R5xdays, as presented in Table 7, indicates a slight decline in trend of Kobo under RCP 8.5 between the years 2050s and 2080s. Meanwhile, an increase in R5xdays will expect at Melkassa during the same period. Additionally, R1xdays will predict to increase in the year 2050s but decrease in 2080s under the aforesaid climate scenario. At the location of Mieso, it is projected that the trend regarding future R1xdays will exhibit a slight increase in the years 2050s and 2080s, while R5xdays are expected to experience a marginal increase during the 2050ss period, followed by a decrease in the 2080s period under the influence of RCP 8.5.

Heavy and very heavy rainfall days (R10 and R20). The projected annual number of days with heavy rainfall (R10) over Melkassa, Mieso, and Kobo showed a decreasing trend under RCP 4.5 and RCP 8.5 in 2050s and 2080s. Although the predicted occurrence of excessively rainy days (R20) in the studied regions is high, the trend of such days will be expected to decreasing in magnitude, but not in a systematic manner (Table 7).

Very and extremely wet days (R95P and R99P). According to the findings presented in Table 7, the analysis reveals that Mieso will be poised to experience non-significant positive trends in the frequency of both very wet (R95p) and extremely wet (R99) days under RCP 4.5 and 8.5 during the both periods (2050s and 2080s). Conversely, Kobo projected to experience a non-significantly decreased frequency of rainy days during the same period, as indicated by the aforesaid data. At the Melkassa location, the analysis of projected future very wet day (R95P) trends indicates an upward trajectory under RCP 4.5 and 8.5 during the time frames (2050s and 2080s). Conversely, there will be an insignificant decrease in the trend of extremely wet days (R99P) under RCP 4.5 regime in the year 2050s, while there is an increase under RCP 8.5 during 2050s, and a decline during 2080s (Table 7).

Total rainfall (PRCPTOT). A trend analysis of projected future total rainfall, as presented in Table 7, will demonstrate a statistically non-significant negative trend across all stations, under both emission scenarios (RCP 4.5 and 8.5), and time frames (2050s and 2080s). The current study discloses that the overall rainfall patterns at three distinct locations, namely, Melkassa in the CRV floor, Miesso in the ERVE, and Kobo in the NRVE, will be projected to experience a non-significant reduction ($P<0.05$) in the order of 1.47, 1, and 3.96 mm/day under the RCP 4.5 by mid-century. Furthermore, by the end of the century, the projected reduction in rainfall will be estimated to be 1.15, 1.07, and 3.65 mm/day for the aforesaid study sites. The total rainfall at aforeside studied sites will decrease statistically non-significantly($P<0.05$) by 1.91, 0.38, and 4.25 mm/day in the mid-century and during the end century will decline in 1.37, 1.8 and 5.2 mm/day. This indicated that the amount of rainfall decreases in the time extent, and the water requirement of rain-fed crops will be affected, thereby increasing increase the water demand for sup-

Table 7. Rainfall indices (per decade) trend in the 2050s and 2080s compared to base period (1989-2019) for the selected three stations Melkassa (CRV floor), Mieso (ERVE) and Kobo (NRVE) of Ethiopia under RCP 4.5 and 8.5 scenarios.

	CRV floor					ERVE					NRVE				
	Melkassa					Mieso					Kobo				
	RCP 4.5			RCP 8.5		RCP 4.5			RCP 8.5		RCP 4.5			RCP 8.5	
	2015	2050	2080	2050	2080	2015	2050	2080	2050	2080	2015	2050	2080	2050	2080
RX1da y	-0.20	-0.058	-0.17	0.023	-0.13	0.25	0.24	0.048	0.24	0.17	0.05	-0.32	-0.096	-0.25	-0.35
RX5da y	0.098	-0.09	-0.062	0.027	0.0008	0.13	0.068	0.076	0.08	-0.02	0.13	-0.5	-0.53	-0.35	-0.58
R10	-0.095	-0.13	-0.14	-0.22	-0.3	-0.07	-0.09	-0.13	-0.3	-0.55	-0.059	-0.1	-0.2	-0.17	-0.12
R20	0.02	-0.19	-0.17	-0.21	-0.25	-0.125	-0.15	-0.14	-.0.16	-0.06	0.055	-0.02	-0.016	-0.07	-0.13
CDD	0.67	0.95	0.72	1.05	0.77	0.67	1	1	1	1	0.33	0.35	0.36	0.17	0.36
CWD	0.04	0.04	0.04	0.04	0.04	-0.1	-0.1	-0.07	-0.25	-0.1	0.18	0.3	0.067	0.3	0.3
PRCPTOT	-0.41	-1.47	-1.15	-1.99	-1.37	-0.43	-1.	-1.07	-0.38	-1.8	-4.16	-3.96	-3.65	-4.25	-5.2
SDII	-0.02	-0.02	-0.018	-0.029	-0.017	0.04	0.06	0.06	0.05	0.06	0.0086	-0.017	-0.0053	-0.08	-0.11
R95P	1.2	1.01	0.84	0.68	1.47	0.72	0.93	0.1	0.64	0.4	-0.35	-1.65	-0.93	-0.81	-0.84
R99P	-0.0003	-0.77	-1.5	0.071	-1.8	1.3	2.2	2.3	2.3	0.02	0.075	-0.18	-0.15	-0.3	-0.28

CRV=central rift valley, ERVE=eastern rift valley escapement, NRVE= northern rift valley escapement.

plementary irrigation, and affecting groundwater potential in the semi-arid Rift Valley region of Ethiopia.

Consecutive dry and wet days (CDD and CWD). The results of the study suggest that the projected future trend of maximum consecutive days with less than 1mm rainfall (CDD) at the Melkassa, Mieso and Kobo study sites will exhibit an insignificant increase during 2050s and 2080s and in RCP 4.5 and 8.5 (Table 7).Alternatively, the projected maximum number of consecutive days with rainfall greater than 1mm (CWD) at Melkassa and Kobo sites will reveal an increasing trend during both time frames (2050s and 2080s) and emission scenarios (4.5 and 8.5) but decrease at Mieso in all conditions. The findings of the study reveal that the projected future consecutive dry days (CDD) featuring a rainfall amount below 1mm (CDD) will expected to exhibit an insignificant increase in trend, while the consecutive wet days (CWD) characterized by a rainfall quantity greater than 1mm (CWD) will predicted to exhibit an insignificant decrease in trend specifically at the locality of Mieso in ERVE under RCP 4.5 and 8.5, within the timeframes of 2050s and 2080s (Table 7). According to a report by the World Bank (2019), it has been confirmed that in East Africa, and particularly in Ethiopia, there is a probability of increased extremity in both dry and wet periods in the forthcoming.

Simple daily intensity index (SDII). The analysis of trends for the projected future SDII reveals a reduction in trend over the Melkassa and Kobo regions, while indicating an upward shift in trend over the Mieso region. This trend is observable across both the RCP 4.5 and 8.5 scenarios, except for a projected decrease in trend at Kobo, specifically in RCP 8.5 during the period spanning 2050s. The major climate extremes that significantly affect various socioeconomic activities are drought and floods, in which understanding the intensity and frequency of extreme is actual significant (Lyon and DeWitt, 2012). The annual projected upcoming rainy day with strong variability characterized with a significant trend during the mid and end century across the studied locations (Table 7). Increasing in the number of CDDS and decreasing in the number of CWDS in the study area, especially during the main rainy season, could affect crop growth and yield, water availability for irrigation, animals, and municipal uses.

3.2.3. Projected future growing season

The changes in the projected future onset and cessation of the main rainy season in the CRV, ERVE and NRVE in comparison with the baseline periods (1989-2019) presented in Table 8. The result reveals that the onset and cessation of the main rainy season as well as the length of the growing period will vary spatially among the stations considered in this study.

Start of the main rainy season (SOS). The projected onset of the rainy season will be expected to delayed in half of the studied sites by 2-4 (Dhera, Melkass and Abomsa) days in the CRV, by 5 (Mieso) days in the ERVE, and by 2 days in all sites in the NRVE during mid-century in RCP 4.5 (Table 8). However, extended in some sites in the CRV by 1-7 (Adami Tullu, Melka werer and Matahara) days and in the ERVE by 3 (Gololcha) days in RCP 4.5 during 2050s. By the 2080s, the onset of the rainy season will be expected to be delayed by 1-14 (Melkassa-Melka Werer). 3 (Mieso) and 1 (Kobo) days in the CRV, ERVE and NRVE, under RCP 4.5. In CRV and ERVE, the projected onset season will be extended by 2-4 days and by 8 days in RCP 4.5 during 2080s. In RCP 8.5 in more than half of the study sites, the onset of the rainy season in 2050s will be expected to be delayed by 1-13.8, 2-3 days in CRV, ERVE, and NRVE respectively (Table 8). The rainy season's onset will be delayed in most of the studies by 2-16, 1-9, and 2-4 days in the same location in 2080s under RCP 8.5 respectively. In CRV and ERVE, the onset will be extended by 4-6 and 3 days, respectively, in 2050s and 2080s. In CRV, it will be extended by 4-6 days in RCP 8.5. NRVE shows no delay in 2050s and 2080s. Moreover, the finding depicts, these changes have been observed in mixed change and more variability in rainy season onset expected in the analyzed areas in the upcoming. There will be more onset of the rainy season variability in RCP 8.5 than RCP 4.5. From the regions CRV is more variable followed by ERVE. Significant changes and variations in the onset of high rainy seasons will expected to occur more frequently in RCP 8.5 when compared to RCP 4.5.

End of the season (EOS). The projected end of the season in all examined sites is expected to be extended in both time frames (2050s and 2080s) and scenarios (4.5 and 8.5) as indicated in Table 8. Specifically, the end of the season is expected to be prolonged by a range of 1-8, 3-4, and 1-3 days in CRV, ERVE, and NRVE areas, correspondingly, under RCP 4.5 during 2050s. Likewise, in these same areas, the end of the season is expected to be extended by a range of 1-4, 2-3, and 1-3 days in RCP 4.5. However, under RCP 8.5, the end of the season is expected to be prolonged by 1-7 and 1-15 days in both time frames (2050s and 2080s). The persistence at the end of the season is expected to exhibit a more noticeable manifestation in the CRV compared to the ERVE and NRVE a outlet.

Length of the growing season (LGS). The expected length of the growing season for the CRV, ERVE, and

Table 8. Projected change of SOS, EOS, and LGP the absolute difference between projected and baseline periods (1989-2019) at different stations in the CRV floor, ERVE and NRVE of Ethiopia.

Feature	Scenarios	Periods	CRV floor						ERVE		NRVE		
			A/Tullu	Melkassa	Dhera	Abomisa	Matahara	M/Werer	Mieso	Gololcha	Kobo	Alamata	Sirinka
SOS		Baseline	189	182	169	183	191	197	200	180	198	201	186
	RCP4.5	2050	3	-2	-2	-4	7	1	-5	3	-2	-2	-2
		2080	4	-1	2	-2	4	-14	-3	8	-1	0	0
	RCP8.5	2050	4	-1	6	-4	-3	-13	-8	3	-3	0	-2
		2080	4	-2	6	-3	-2	-16	-9	-1	-3	-4	-2
EOS		Baseline	276	276	282	284	275	275	275	283	275	275	275
	RCP4.5	2050	1	2	2	8	1	0	3	4	3	3	1
		2080	0	2	2	4	1	0	3	2	3	2	1
	RCP 8.5	2050	1	1	2	7	1	0	3	3	2	2	1
		2080	1	8	5	15	2	0	4	10	4	3	3
LGP		Baseline	87	96	113	101	85	78	75	103	77	74	89
	RCP 4.5	2050	-3	2	2	2	1	-1	8	1	5	4	3
		2080	-4	-1	1	1	-4	12	0	-6	3	2	0
	RCP 8.5	2050	-3	0	-4	3	3	9	10	0	5	-1	3
		2080	-4	8	-1	10	3	14	12	11	7	7	5

CRV=central rift valley, ERVE=eastern rift valley escapement, NRVE= northern rift valley escapement.

NRVE regions during the period of 2050s under the RCP 4.5 scenario is projected to increase by 1-2, 1-8, and 3-8 days, respectively (Table 8). However, in the CRV and NRVE regions, the expected extension is projected to be upto12 and 3 days, respectively, during 2080s, while ERVE is expected to remain unchanged during the same period. Under the RCP 8.5 in some studied sites, the length of the growing season is expected to be prolonged by 3-9, 10, and 3-5 days, respectively, in the CRV, ERVE and NRVE during 2050s respectively. Additionally, in the same regions and scenario, the projected extension is expected to be 3-14, 11-12, and 5-7 days in 2080s, respectively. The existing empirical evidence suggests that significant heterogeneity exists regarding the length of the growing period in the areas under analysis. The current study presents a significant observation regarding deviation levels, which exhibit a pronounced increase in the CRV when compared to the ERVE and NRVE.

The present investigation focuses on examined regions, wherein the projected growing season characteristics including onset, end, and length exhibit notable variations and modifications within two distinct time frames, namely 2050s and 2080s, as well as under distinct scenarios: 4.5 and 8.5, when compared with the base period. Therefore,the findings suggest that alterations to agricultural practices, such as adjusting planting timing and utilizing sorghum varieties with early or medium maturation periods, may be necessary for farmers in the region to address the changes observed in onset and cessation dates. Management measures related to soil, particularly those addressing flooding and water logging problems, must receive considerable attention.

4. CONCLUSIONS AND RECOMMENDATIONS

The study shows an increasing projected annual and seasonal minimum and maximum air temperatures in the Sami-arid rift valley of Ethiopia based on both emission scenarios (RCP 4.5 and 8.5) and time frames (205 and 2080s). The change in the projected future mean air temperature is more dramatic in minimum air temperature than maximum air temperature, and the magnitude of the change depends on location, emission scenarios, and time frames. The results of the analysis suggest that, at RCP 4.5, CRV is projected to exhibit higher air temperatures than two other regions, namely, ERVE and NRVE, in 2050. However, under RCP 8.5, NRVE is expected to experience greater levels of warmth during 2080 than 2050. The result shows that, during the main growing season, the NRVE will be warmer followed by CRV in subsequent order. Hottest day and night temperatures and their frequencies will increase in both time frames (2050s and 2080s) and scenarios at Melkassa and Mieso stations. However, the trend for the projected hottest days will decrease non-significantly, while the hottest nights, day and night frequency will increase under RCP 4.5 and 8.5 at Kobbo during 2050 and 2080.

The percentage change of mean annual rainfall is projected to a mixed change in the stations located in CRV and ERVE, whereas, in NRVE it will projected to increase under RCP 4.5 in 2050s. However the projected annual rainfall under RCP 4.5 in 2080s will be decline in the analyzed semi-arid rift valley of Ethiopia. In most of the location in CRV and ERVE stations the projected rainy season rain will be decline, whereas, in NRVE it will projected to increase in period of 2050s under RCP 4.5. Rainfall will decrease in semi-arid rift valley except Abomsa during the main rainy season in 2080s under RCP 4.5. Future maximum average rainfall for R1xdays and R5xdays will decrease at Melkassa and Kobo, while in Mieso, a slight upward trend in 2050s and 2080s under RCP 4.5. In Kobo's R1xdays and R5xdays slightly decline by 2050s and 2080s under RCP 8.5. The annual heavy rainfall days (R10)will decrease in Melkassa, Mieso, and Kobo under RCP 4.5 and RCP 8.5 in 2050s and 2080s. Very heavy rainfall days (R20) days will still occur to decrease in magnitude. The trend analysis of R95P will experience to increase at Melkassa and Mieso but decrease at Kobbo in both time frames (2050s and 2080s) and scenario (4.5 and 8.5). While, the projected R99P will experienced to mixed change at Melkassa and decline at Kobo in both time frames(2050s and 2080s) and scenario(4.5 and 8.5). A trend analysis of projected future total rainfall (PRCPTOT) will demonstrate a negative trend across all stations, under both emission scenarios (RCP 4.5 and 8.5), and time frames (2050s and 2080s). This study shows that rainfall (PRCPTOT) patterns in Melkassa, Miesso, and Kobo will have reducting pattern by 2050s with RCP 4.5. Study results suggest CDD trends will insignificantly increase at Melkassa, Mieso, and Kobo by 2050s and 2080s under RCP 4.5 and 8.5. CWD trend will increase at Melkassa and Kobo, but decrease at Mieso in all conditions.

Additionally, the result reveals that the annual and main rainy season rainfall, onset, ends, and the length of growing period will vary spatially among the stations considered for the study. This would influence moderate variations in LGP in some stations. Consequently, the finding highlights the position of site-specific efforts to increase local adaptive capacity. Thus, farmers in the region might require a modification in agricultural operations such as planting time, early or medium maturing sorghum verity corresponding to the modification in onset and cessation dates. Furthermore, attentions needs to be given the management measures related to soil and moisture conservation practice in the studied areas.

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