GSJ: Volume 10, Issue 11, November 2022, Online: ISSN 2320-9186
www.globalscientificjournal.com

INVESTIGATING PROJECTED CLIMTE VARIABILITY AND THEIR TRENDS IN THE CASE OF SOUTH GONDAR DISTRICT AMHARA, ETHIOPIA

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September 2022
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ABSTRACT

Characterizing seasonal climate variability in terms of rainfall and temperature variables and associated trend is important for planning. On basis of this, a study was conducted in south Gondar district, to investigate variability and its trend. I used the models of Markism weather generator to downscale projected mid-century (2040-2069) rainfall and temperature variables and implications of the future climate with production of major crops (teff, barley, wheat)is analyzed. Accordingly 8 rain fall and 5 temperature variables were analyzed for variability measures (coefficient of variation, standard deviation, standardized anomaly) and trend test using Mann-Kendall's test. The results revealed spatial and temporal variability and significant only for few which were spatially non-systematic under the worst scenario. Similarly predictions of the future mid-century revealed high variability for the start of season among others. The trends were also variable and incoherently significant only for very few variables which lack spatial consistence in direction of changes over the base period though models agree on increased warming where as both NRD and TRF was increasing over the projected period. Nevertheless, the predicted increase in future mid-century warming may result in crop area relocation and yield reduction. Hence it can be concluded that the climate of south Gondar district is characterized by spatial and temporal variability, increasing and deceasing trend in temperature and rainfall variables respectively, With strong negative effect on crop production, and there is a need to adapt the variable climate develop and diversify heat stress tolerant and moisture efficient crop varieties to combat anticipated changes in crop production and productivity eshu.

Keywords: climate variability, crop production, south Gondar district, trends

1. **INTRODUCTION**

Projected climate change is the decisive factor for a country to determine its economy. Today climate change becomes one of the most important issues, and the biggest concern of humankind. As a consequence of increased concentration of atmospheric greenhouse gases (GHG), temperature is increasing and the amount and distribution of rainfall is becoming variable. According to the Intergovernmental Panel on Climate Change (IPCC) reports, global average temperature has increased over the last century and is expected to rise by 1.4 and 5.8°C by 2100 (IPCC, 2014a) with the doubling of the current CO_2 concentration in the atmosphere (Cubasch *et al.*, 2001).

Associated with this unprecedented global warming, climate variability and the associated changes in frequency and intensity of extreme weather events such as drought, cold and heat waves, floods, cyclones and hails are also increasing worldwide (Marvi and Tupper, 2004; Mannava and Raymond, 2007; Ninan and Satyasiba, 2012). As a result, many studies have shown that the frequency, duration, and severity of drought have significantly increased due to climate change in Africa, Eastern Asia, Mediterranean region, and Southern Australia since 1951 (viste *et al.,* 2012,Spinoni *et al.*, 2013). In many cases globally days are becoming warmer and rainfall is more variable and irregular (IPCC, 2009).

In Ethiopia, where over 85% of the population is directly dependent on agriculture for employment and subsistence, and almost 50% of the GDP and export earnings of the country are reliant on climate sensitive sector, rainfall variability and drought are not a new phenomenon (Tuffa, 2012). However, its frequency of occurrence and intensity has repeatedly increased during the past few decades. Over the last 55 years alone the country experienced increase in minimum and maximum temperatures, and numerous episodes of extreme dry and wet years that caused significant damage to life, property, natural resources and the whole economy.

Moreover, the country's farming systems have been subjected to variability and fluctuations in production due to inter-annual and seasonal variability of rainfall (Bewket, 2009) which in many cases translated in to cycles of episodic food crises that labeled the country as one of the "most vulnerable in the world". Consequently, the impacts caused by extreme droughts to the economy are estimated to be equivalent to the annual overseas development assistance received (Oxfam International, 2009).

Nevertheless, the agricultural and livelihood impacts of climate variability and climate change varies from region to region and largely depend on other factors such as farm land size, the soil types, type of crops grown, topography, and use of improved technologies as well as future rain fall and temperature variables .

The Amhara National Regional State in general and the South Gondar district in particular, where land holdings have been under continuous sharing and fragmentation. Many farmers are having very small farm land size, and are unable to compensate for unit area yield loss by increasing area of production; where land is under continuous cultivation without resting , and where low or no external input use characterize the farming system, impacts of climate variability and change is expected to be more important as well as the future rain fall and temperature should be studied.

A study conducted by Bewket (2009) showed that there is a strong correlation among monthly, annual and seasonal total rainfall, and cereal production. However, the study of Bewkwt (2009) failed to provide detailed account on the most important elements of climate variability indices of extreme rainfall and temperatures that have far reaching effect than the long term mean changes.

On the other hand, analysis of climate data of weather stations located in the region showed that there is marked spatial and temporal variability among weather stations in annual and seasonal rainfall totals (Bewket, 2009; Hadigu,2013; Getaneh,2015). This indicates the possibility of existence of local level variation in all other elements of climate variability and change detection indices. The recent work of Getaneh (2015) on rainfall variability and its implication on crop production in the North Eastern part of Amhara Region attests this. Hence the general objective of this study was to analyze future climate variability and trends in terms of agriculturally important rainfall and temperature parameters in the South Gondar district of the Amhara National Regional state of Ethiopia with the following specific objectives:

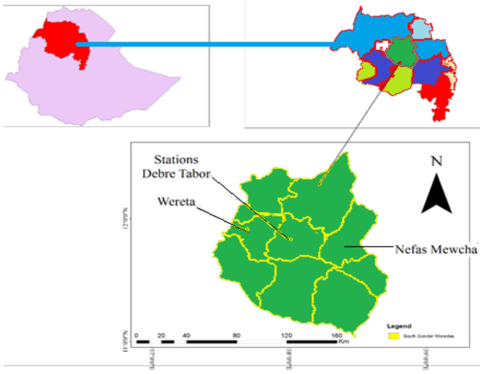
- ✓ to analyze the future rainfall variability and trends
- ✓ characterize future temperature variability and trends
- ✓ to explore the implications of the future climate on crop production

2. MATERIAL AND METHODS

3.1. Description of the Study Area

The study was conducted in the South Gondar Zone of the Amhara National Regional State of Ethiopia. The study area covers 14,669.99 square Kilometers.

Figure 1.Location map of the study area



The district is located in between 37.677 ° and38.524 ° E longitudes, and 11.325 ° and 12.421 ° N latitude. The district shares administrative boundaries with West Gojjam Zone in West, North Gondar Zone in North, East Gojjam Zone in South, South Wollo Zone in East and North Wollo Zone in the North East.

The climate of the study area is characterized by Woyina Dega (warm zone) between 1500 - 2500 m above sea level , Kola (hot zone) below 1500 meters above sea level, and Dega (cold zone) above 2500 m above sea level. The annual mean temperature of the Zone is between 15°C and 21°C, but in valleys and marginal areas the temperature exceeds 27°C (Astatkie, 2012). The study area is highly variable in terms of rainfall.

The study region experiences a mono modal rainfall that begins from March-April and gradually reach peak in months from June-September and then recedes. As a result crop production in the study region is solely dependent on main rain season. The dominant soil type of the study area is visrte sols (FAO 1984) while the crops grown in the study area are barley, wheat, *Teff*, sorghum, maize, field beans, peas, chickpeas, and oil crops like linseeds and *Nug* as well as root and tuber crops like potato. *Teff* is the dominant crop grown in low and mid altitude areas while wheat and barley are dominating the mid and highland areas, respectively. According to Astatkie (2012) annual crop production in the study area is less, and could not meet the food need of local farmers throughout a year.

3.2. Data Source and Station Selection

3.2.1. Future Climate Data

Future daily rainfall, maximum and minimum temperatures data was downscaled using Markism weather generator from CSIRO and MIROC models under RCP 4.5 and RCP 8.5 emission scenarios for the period of Mid-century. Markism is a third-order markov of chain rainfall generator used for daily rainfall, maximum and minimum temperatures simulator GCM based on grid points. Therefore the three weather stations (Nefas Mewcha, Debre Tabor and Werota) were selected for the study on bases of spatial representation of the Zone.

Table 1 Description of weather stations selected for the study in the South Gondar Zone, Amhara National Regional State, Ethiopia

Where: RF is Rainfall, Tmax is maximum temperature, Tmin is minimum temperature

Station name	Latitude (^{o}N)	Longitude (^{o}E)	Altitude (M)	Climate Data	Missing data (%)		
					RF	Tmax	Tmin
Debre Tabor	11.89	37.98	2612	2040-2069	-	-	-
Nefas Mewcha	11.81	38.36	3098	2040-2069	-	-	-
Werota	11.92	37.69	1819	2040-2069	-	-	-

3.3. Data Quality Control

3.3.1. Outlier Detection

Since identification of outliers (suspicious data) is the primary emphasis of climate database development, the Turkey fence method was used for trimming outliers (Ngongondo *et al.*, 2011) in order to reduce the size of the distribution tails to a safer non-resistant homogenization as indicated in Gonzalez-Rouco *et al.* (2001) and Ngongondo *et al.*(2011). The data range was represented as:

$$Q_1 - 1.5 * IQR, Q_3 + 1.5 * IQR$$

Where: Q1 and Q3 were lower and upper quartile ranges respectively, IQR was an interquartile range, 1.5 were standard deviation from mean. Mean values, outside the turkey fence were considered as outliers.

3.4. Climate variables

3.4.1. Rainfall variables

The rainfall variables studied in the projected climate data includes: onset date, end date, length of rainy season, dry spell length, number of wet days , number of rainy days, and consecutive wet days. Each of which were determined as follows: the onset date of rainy season was determined as the date when 20 mm or more rainfall was accumulated over three consecutive rainy days for the growing season and no dry spell greater than 7 days in the next 30 days as in Tesfaye and Walker (2004). On the other hand, end date of rainy season was determined using soil water balance model of FAO (1978) where the date when soil water balance becomes zero (0) mm after September first as indicated in Tesfaye and Walker (2004), and, Getaneh (2015). Whereas, the length of the growing seasons was determined as the difference between the onset date and end date of the season as indicated in Mamo (2005), Feyera *et al.*, *(* 2013), Hadgu *et al.*,(2013) and Hadgu *et al.*, (2014). Also number of rainy and dry days were determined by counting all days with rainfall greater than or equal to 1mm as rainy day and those days with less than 1 mm rainfall as dry days, respectively as outlined in NMSA (2001), Segele and Lamb (2005) and Getaneh (2015). Similarly total rainfall was determined as sum of rainfall of each day during the crop growing period as indicated in NMSA(2001), Segele and Lamb(2005), Mesay(2006) and Hadgu *et al*.(2013). Dry spell length was also determined as consecutive days with rainfall less than 1 mm per day exceeding 7, 9, 10 and 15 days and analyzed by Markov Chain analysis as indicated in Stern *et al.,(* 2006) and Stern and Cooper (2011) using INSTAT v3.36. **Temperature variables**

The temperature parameters studied include: mean seasonal maximum, mean seasonal minimum, mean seasonal.

Each of which were determined as follows: the mean seasonal maximum, and mean seasonal minimum temperatures were determined as mean of the sum of the daily maximum and daily minimum temperatures recorded, respectively during the crop growing season, while the mean seasonal temperatures are determined as average values of the daily maximum and minimum temperatures recorded for the crop growing season.

3.5. Crop variables

The crop variables studied include: annual area of production which was determined as the annual area (ha) devoted to each of the major crops (*Teff*, Barly and wheat) grown in the Zone during the study years (1990-2019) ; annual yield was determined as the amount of grain yield (quintal) obtained from each of the major crops grown in the Zone during the study years; Productivity: was estimated as the amount of grain yield obtained per unit of land (ha) from the major crops grown in the Zone during the study years.

3.6. Variability Analysis

Variability in rainfall and temperature variables/parameters were analyzed using descriptive statistics (frequency, mean), coefficient of variability, standardized anomaly index and standard deviations.

The SAI was calculated as the difference between the total of a particular year and the long term average records divided by the standard deviation of the long term data as following:

SAI (Z) =$\left(\frac{X-\mu}{\delta}\right)$…….1

Where, Z was the standardized rainfall or temperature or crop anomaly; x was the crop growing seasonal rainfall total or mean crop growing season temperature of a particular year; μ was the mean crop growing season rainfall over a period of observation and δ was the standard deviation of crop growing season rainfall over the period of observation.

Coefficient of variation (CV) was also calculated to evaluate the variability of all parameters/variables in the study and its characteristics by dividing the standard deviation of the event to its mean. Coefficient of variation was computed as:

CV=$\left(\frac{\delta}{\bar{X}}\right)100$…….2

Where CV was the coefficient of variation; X was the average long-term rainfall or temperature over the given decade and δ was the standard deviation.

Based on CV the degree of variability was classified as less, for CV< 20%, as moderately for CV from 20% to 30%, and as high for CV > 30% as indicated in Hare (1983). Moreover, based on values of standard deviation (SD) it was classified as less stable for SD > 40, as moderate for

SD 20-40, as highly sable for SD 10-20 , and very high stability for SD <10 after Reddy (1990).

3.7. Trend Analysis

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

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn\left(X_j - X_i\right) \text{……..3}$$

Where S was the Mann-Kendal's test statistics; *x*i and *x*j were the sequential data values of the time series in the years *i* and *j* (*j*>*i*) and *N* was the length of the time series. A positive *S* value was interpreted as indicative of an increasing trend and a negative value as indicative of a decreasing trend in the data series. The sign function was given as:

$$sgn\left(X_j - X_i\right) = \begin{cases} +1 \; if\left(X_j - X_i\right) > 0 \\ 0 \; if \; \left(X_j - X_i\right) = 0 \\ -1 \; if\left(X_j - X_i\right) < 0 \end{cases} \quad \text{……4}$$

The variance of *S*, for the situation where there could be ties (that was, equal values) in the *x* values was given by:

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

Where *m* was the number of tied groups in the data set and *ti* was the number of data points in the i^{th} 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

$$Z_{MK} = \begin{cases} \dfrac{s-1}{\sqrt{\text{var}(s)}} \; Ifs > 0 \\ 0 ifs = 0 \\ \dfrac{s+1}{\sqrt{\text{var}(s) ifs < 0}} \end{cases} \text{……..…6}$$

The presence of a statistically significant trend was evaluated using the ZMK value. In a two-sided test for trend, the null hypothesis Ho was accepted if $|Z_{MK}| < Z_{1-\alpha/2}$ at a given level of significance. Z1-α/2 was the critical value of ZMK from the standard normal table. In the present study significance level of a trend was examined under at 5% probability level. The slope (change per unit time) was estimated following the procedure of Sen (1968) which was computed as:

$$T_i = \frac{\left(X_j - X_k\right)}{j-k} \; fori = 1,2,3,....N \text{ ……….7}$$

Where: X_j and Xk were data values at time k, (j>k), correspondingly. The median of these N values of T_i was represented as Sen's estimator of slope given by

$$Q_i = \left\{ \begin{array}{l} T(\frac{T+1}{2}) \text{.......} N = Odd \\ \left\{ T\frac{N}{2} + T(\frac{N+2}{2}) \right\} \text{.....} N = even \end{array} \right\} \text{……8}$$

Sen’s estimator was computed as Qmed=T (N+1)/2 if N appeared odd and it was considered as Qmed= (TN/2+T (N+2)/2 if N appeared even. At the end, Qmed was computed by a two sided test at 100 (1- α) % confidence interval and then a true slope was obtained by the non-parametric test. Positive values of Q was interpreted as indicative of an upward or increasing trend, and the negative values were interpreted as indicative of decreasing trends and in case if the values were zero, it was taken as indicative fluctuations in the data series around the mean as indicated in Sen (1968). The computations were done using the MAKESENS_1_0 excel based template (https://www.google.com.et/.

4. RESULTS AND DISCUSSIONS

4.1. Characteristics of Projected mid-century (2040-2069) Climate

This subsection presents results of the projected mid-century (2040-2069) future climate (rainfall and temperature) variability and associated trends.

4.1.1. Projected mid-century rainfall variability

Projected future *Kiremt* rainfall of the South Gondar Zone showed variability among models, scenarios and weather stations (Table 3). The seasonal rainfall varied from the minimum of 412mm as predicted by CSIRO under RCP 4.5 at Nefas Mewcha to 2176 mm predicted by MIROC under RCP 8.5 at Werota. On the other hand, the CSIRO predicted the minimum *kiremt* rainfall of 747mm under RCP 4.5 at Nefas Mewcha and a maximum of 1992 mm under RCP 8.5 at Werota. Similarly, the MIROC model predicted from the minimum of 485 mm under RCP 4.5 at Nefas Mewcha to the maximum of 2176 mm under RCP 8.5 at Werota.

The projected coefficient of variability (CV) for the future mid-century seasonal rainfall totals also varied from 148% at Nefas Mewcha to 221 % at Debre Tabor as predicted by CSIRO under RCP 4.5 scenario, and from 166% under RCP 4.5 at Nefas Mewcha to 256% at Werota under RCP 8.5 as predicted by the MIROC. The observed high CV value could be an indication of very high variably of the future kiremt rainfall in the south Gondar Zone. In line with this Gissila *et al.* (2004), also reported that the total June–September rainfall over the whole regions of the country is more variable and is difficult to predict. Similarly, the predicted SD values of the present study also varied from19-20mm as which could classified as moderately stables as described by Reddy (1990) .

Table 2 Summary statistics of the projected seasonal kiremt rainfall totals of future mid-century at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (2040-2069).

Statistics	**CSIRO -RCP4.5**	**CSIRO- RCP8.5**	**MROC- RCP4.5**	**MIROC- RCP8.5**
		Debre Tabor		
Max (mm)	1673	1673	1514	1910

Mean(mm)	1127	1127	1021	1204
Min (mm)	707	747	641	757
SD (mm)	19	20	19	20
		Werota		
Max (mm)	1811	1992	2107	2176
Mean (mm)	1127	1205	1300	1341
Min (mm)	747	790	879	256
SD (mm)	19	19	19	19
		Nefas Mewcha		
Max (mm)	1230	1394	1394	1478
Mean (mm)	747	817	817	910
Min (mm)	412	485	485	502
SD (mm)	19	20	20	19
		Areal average		
Max (mm)	1571	1685	1402	1854
Mean (mm)	1000	1049	1046	1151
Min (mm)	622	674	668	334
SD (mm)	19	19	19	19

SD is standard deviation.

4.1.1.1. Start of season (SOS) in mid-century

The start date (SOS) of future mid-century growing season predicted by the CSIRO, and the MIROC models under RCP4.5 and RCP 8.5 emission scenario is presented in Table 6. As shown in the table, models differed in prediction of the future mid-century SOS of the season. For CSIRO the predicted earliest SOS will be on DOY 61(March-1) under RCP 8.5 at Nefas Mewcha , and the latest SOS will be on DOY202 (Jul-20) under RCP 4.5 at Debre Tabor weather stations. The MIROC model on the other hand, predicted the SOS to vary from the earliest start on DOY 61 (March-1) under both emission scenarios at Nefas Mewcha to the latest start on DOY 195 (Jul-16) under RCP4.5 at Debre Tabor. The coefficient of variability (CV) for the future mid-century SOS, however, revealed moderate to less variability for all models under both scenario which could be classified as less variable (Hare ,1983) except at Nefas Mewcha . Moreover, the projected SOS was early under the low emission scenario at Debre Tabor weather station when compared to that of the Nefas Mewcha and Werota. (Table 3)

Table 3. Summary statistics of projected start of Kiremt growing season (SOS of future mid-century at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (2040-2069).

variable	**Statistics**	CSIRO – RCP4.5	CSIRO- RCP8.5	MIROC- RCP4.5	MIROC- RCP8.5
			Debre Tabor		
SOS	Latest (DOY)	202(july 20)	195(july 16)	195(july 16)	195(july 16)
	Mean (DOY)	166	154	148	154
	Earliest (DOY)	98	103	94	103
	CV%	17	16	22	17
	SD	26	25	33	26
			Nefas Mewcha		

SOS	Latest (DOY)	190(Jul-8)	187(Jul-5)	187(Jul-5)	178(Jun-26)
	Mean (DOY)	155(Jun-3)	142(May-21)	142(May-21)	138(May-17)
	Earliest (DOY)	72(Mar-12)	61(Mar-1)	61(Mar-1)	61(Mar-1)
	CV%	23	26	26	24
	SD	35	38	38	33
			Werota		
SOS	Latest (DOY)	185(Jul-3)	179(Jun-28)	174(Jun-22)	174
	Mean (DOY)	155(Jun-3)	152(May-31)	149(May-28)	149
	Earliest (DOY)	105(Apr-14)	107(Apr-16)	107(Apr-16)	107
	CV%	13	13	13	13
	SD	20	21	19	19
			Areal/Zonal Ave		
SOS	Latest (DOY)	192(Jul-13)	195(July 16)	183(July 14)	(July 16)195
	Mean (DOY)	159(July-7)	154(July-2)	147(May-26)	148(May-27)
	Earliest (DOY)	92(Apr-1)	103(Apr-12)	84(Mar-24)	94(Apr-3)
	CV%	18	16	20	22
	SD	27	25	30	33

DOY is day of the year, CV is coefficient of variation, SD is standard deviation

4.1.1.2. End of season (EOS) in mid-century

The probable end of growing season (EOS) predicted by climate models of CSIRO will vary from the earliest end on DOY226 (August-16) under RCP 4.5 at Werota to the latest end on DOY 328 (Nov- 23) under RCP 4.5 at Debre Tabor (Table 5). On the other hand, the MIROC model predict the EOS of future growing season from the earliest end on DOY226 (August-16) under RCP 4.5 at Werota to the latest end on DOY335 (Nov-30) under RCP 8.5 scenario at Debre Tabor.

Among the climate models MIROC under the worst scenario (RCP8.5) predicts the longest probable end of growing season (EOS) which is at November thirty, Whereas CSIRO model predicts the shortest end of growing season (EOS) under (RCP 4.5) scenarios.

The projected CV and SD for the future EOS revealed less variability and moderate to high stability by all GCMs at all studied stations (Table 4).

This implies that by mid- century the projected EOS of future growing season will vary over a short time span and that the patterns of EOS will be expected to be more understood, and decisions pertaining to harvesting and storage will probably be made more easily. On the other hand, end of the projected season was predicted as less variable at Nefas Mewcha than at Debre Tabor and Werota by the CSIRO and MIROC climate models under RCP 4.5 emission scenarios, whereas, at Debre Tabor and Werota, both climate model under low emission scenario predicted more variable end of season in the mid-century

Table 4. Summary statistics of projected end of season of Kiremt growing season of future mid-century at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (2040-2069)

variable		CSIRO-RCP4.5	CSIRO- RCP8.5	MROC- RCP4.5	MIRO -RCP8.5
			Debre Tabor		

EOS	Latest (DOY)	328(Nov-23)	327(Nov -22)	327(Nov -22)	335(Nov-30)
	Mean (DOY)	288(Oct-14)	286(Oct-12)	286(Oct-14)	288(Oct-14)
	Earliest (DOY)	270(Sep-26)	270(Sep-26)	270(Sep-26)	270(Sep-26)
	CV%	4	4	4	5
	SD	13	12	12	14
Nefas Mewcha					
EOS	Latest (DOY)	312(Nov-7)	312(Nov-7)	314(Nov-9)	316(Nov-11)
	Mean (DOY)	274(Sep-30)	268(Sep-24)	270(Sep-26)	273(Sep-29)
	Earliest (DOY)	246(Sep-2)	246(Sep-2)	246(Sep-2)	246(Sep-2)
	CV%	8	8	9	9
	SD	24	22	24	25
Werota					
EOS	Latest (DOY)	312(Nov-7)	312(Nov-7) ()	312(Nov-7)	326(Nov-11)
	Mean (DOY)	270(Sep-15)	264((Nov-20)	263((Nov-19)	298(Oct-24)
	Earliest (DOY)	226(Aug-16)	246(Sep-2)	226(Ag-16)	274(Sep-30)
	CV%	8	8	8	5
	SD	22	22	22	16
Areal/Zonal Average					
EOS	Latest (DOY)	317(Nov-12)	327(Nov-22)	312(Nov-7)	321(Nov-16)
	Mean (DOY)	227(Aug -17)	286(Oct-12))	266(Aug-13)	278(Otc-4)
	Earliest (DOY)	247(Sep-3)	270(Sep-26)	246(Sep-2)	278(Oct-4)
	CV%	7	4	8	7
	SD	20	12	22	18

NB: DOY is day of the year CV is coefficient of variation, SD is standard deviation

4.1.1.3. Length of growing season (LGS) in mid-century

With regard to the predicted future length of growing season (LGS), the predictions by CSIRO varied from the shortest LGS of 61 days under RCP 4.5 emission scenario at Werota to the longest LGS of 219 days under RCP 4.5 at Nefas Mewcha (Table 8). On the other hand, the MIROC model predicted future LGS to be in the range of 69 days at Debre Tabor to the longest 225 days under RCP 8.5 emission scenarios at Nefas Mewcha weather stations (Table 5). The projected mean LGS of future growing season as predicted by CSIRO model varied from 103 days under RCP 4.5 at Nefas Mewcha to 119 days under RCP 4.5 emission scenario at Werota. On the contrary, the MIROC model predicted the mid-century LGS in ranges from 108 day under RCP 4.5 at Nefas Mewcha to 122 days under RCP 8.5 at Werota (Table.8) The two GCMs (CSIRO and MIROC) predicted moderate coefficient of variation (CV) and moderate stability of SD values of LGS under RCP4.5 and RCP 8.5 emission scenario. Moreover, among the two emission scenarios, minimum and maximum length of growing seasons were predicted at Nefas Mewcha by CSIRO GCM under RCP 4.5 scenarios, indicating relatively better condition for growing crops.

Table 5. Summary statistics of projected Length of growing season (LGS) of future mid-century at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia(2040-2069).

GCM	Emission scenario	Statistics	Debre Tabor	Nefas Mewcha	Werota	Areal average
CSIRO	RCP4.5	Maximum(days)	157	219	190	189
		Mean(days)	155	103	119	126
		Minimum(days)	70	70	61	67
		Median	118	93	120	110
		CV%	23	33	26	27
		SD(days)	20	32	31	28
	RCP8.5	Maximum(days)	158	173	187	173
		Mean(days)	116	105	116	112
		Minimum(days)	71	77	69	72
		Median	113	95	121	110
		CV%	22	26	26	25
		SD(days)	18	25	30	24
MIROC	RCP4.5	Maximum(days)	150	198	189	179
		Mean(days)	113	10	122	82
		Minimum(days)	70	70	73	71
		Median	112	93	123	109
		CV%	19	35	26	27
		SD(days)	21	35	31	29
	RCP8.5	Maximum(days)	160	225	190	192
		Mean(days)	112	111	124	116
		Minimum(days)	69	71	73	71
		Median	114	95	163	124
		CV%	20	32	26	26
		SD(days)	23	36	33	31

LGS is length of the growing season

4.1.1.4. Number of rainy days (NRD) in mid-century

The projected mid-century number of rainy days also varied among weather stations as predicted by CSIRO and MIROC under RCP 4.5 and RCP 8.5 emission scenarios (Table 6). As per the CSIRO RCP4.5, among weather stations, more number of rainy days on average (88 day) were predicted to occur at Debre Tabor and the least (76 day) at Nefas Mewcha. Similarly the CSIRO 8.5 predicted more number of rainy days on average (89 days) at Debre Tabor and the least (76 day) at Nefas Mewcha and werota.

Table 6. Summary statistics of predicted Number of Rainy Days (NRD)for future mid-century at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia(2040-206)

GCM	Emission scenario	Statistics	Debre Tabor	Nefas Mewcha	Werota	Areal average
CSIRO	RCP4.5	Maximum(days)	106	90	90	95
		Mean(days)	88	76	76	80
		Minimum(days)	73	59	59	64
		CV%	10	9	9	9
		SD(days)	8	8	8	8
	RCP8.5	Maximum(days)	107	90	90	96
		Mean(days)	89	76	76	80
		Minimum(days)	74	59	59	64
		CV%	10	10	10	10
		SD(days)	8	8	8	8
MIROC	RCP4.5	Maximum(days)	106	90	90	95
		Mean(days)	88	76	76	80
		Minimum(days)	73	59	59	64
		CV%	10	9	9	9
		SD(days)	8	8	8	8
	RCP8.5	Maximum(days)	106	92	92	97
		Mean(days)	89	77	77	81
		Minimum(days)	75	61	61	66
		CV%	9	10	10	10
		SD(days)	8	8	8	8

CV is Coefficient of Variation, NRD is Number of Rainy Days and SD is Standard Deviation.

The MIROC 4.5 also predicted more number of rainy days on average (88 day) at Debre Tabor and the least (76 day) at Nefas Mewcha (Table 9). Similarly the CSIRO 8.5 predicted more number of rainy days on average (89 days) at Debre Tabor and the least (77 day) at Nefas Mewcha. At the same time as predicted by both models and the emission scenarios maximum number of NRD were recorded at Debre Tabor and the minimum at Nefas Mewcha which might indicate better rainfall scenarios at Debre Tabor over Nefas Mewcha, whereas the observed coefficient of variation (CV) and the standard deviation (SD) values were the same being equally 8 for all weather stations indicating the same level of less variability and very high stability and predictability of the number of rainy days as indicated by Hare (1983) and Reddy (1990),.

4.1.1.5. Number of dry days (NDD) in mid-century

The number of future dry days in the mid-century projected by CSIRO and MIROC under RCP 4.5 and RCP 8.5 (Table 10) showed that contrary to the aforementioned number of rainy days, among weather stations the CSIRO 4.5 predicted more number of dry days on average (46 day) to occur at Nefas Mewcha and the least (76 day) at Debre Tabor with the highest (36 days) range of difference between the maximum and minimum for the study period at Werota and the least (31 days) at Nefas Mewcha. Similarly the CSIRO 8.5 predicted more number of dry days on average (45 day) to occur at Nefas Mewcha and the least (32 day) at Debre Tabor with the highest (33 days) range of difference between the maximum and minimum for the study period at Debre Tabor. the MIROC under RCP 4.5 predicted more number of dry days on average (45 day) at Nefas Mewcha and the least (33 day) at Debre Tabor with the highest (33 days) range of difference between the maximum and minimum for the study period at Werota and the least (31 days) at Nefas Mewcha. Similarly the MIROC 8.5 predicted more number of dry days on average (44 day) to occur at Nefas Mewcha and the least (32 day) at Debre Tabor with the highest (33 days) range of difference between the maximum and minimum for the study period at Werota which might indicate relatively less drought risk at Debre Tabor over Nefas Mewcha, whereas the observed coefficient of variation (CV) and SD under both GCMs and emission scenarios revealed less than 20% at Nefas Mewcha indicating less variable condition and very high stability and predictability, whereas under both GCMs and emission scenarios, it was above 20% for Debre Tabor indicting modernly variable scenario as per Hare (1983) and Reddy (1990).

Table 7. Summary statistics of predicted Number of Dry Days (NDD) of future mid-century at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia(2040-2069)

NDD is Number of dry days, CV is Coefficient of Variation and SD is Standard Deviation.

GCM	**Emission scenario**	**Statistics**	**Debre Tabor**	**Nefas Mewcha**	**Werota**	**Zonal average**
CSIRO	RCP4.5	Maximum(days)	49	63	57	56
		Mean(days)	33	46	41	40
		Minimum(days)	16	32	26	25
		CV%	25	17	19	20
		SD(days)	8	8	8	8
	RCP8.5	Maximum(days)	48	63	56	56
		Mean(days)	32	45	41	39
		Minimum(days)	15	32	25	24
		CV%	26	17	19	21
		SD(days)	8	7	8	8
MIROC	RCP4.5	Maximum(days)	50	63	55	56
		Mean(days)	33	45	39	39
		Minimum(days)	16	32	22	23
		CV%	26	17	20	21
		SD(days)	8	7	8	8
	RCP8.5	Maximum(days)	47	61	55	54
		Mean(days)	32	44	40	39
		Minimum(days)	16	30	23	23
		CV%	25	17	20	21
		SD(days)	8	7	8	8

4.1.1.6. Rainfall anomaly in mid-century

The future rainfall anomaly for the mid-century projected by the CSIRO and MIROC models under RCP4.5 and RCP8.5 emission scenarios (Table 8) showed that with CSIRO under RCP4.5, at Debre Tabor, there will be more number of positively anomalous years were sixteen years are expected to have rainfall above the long term mean while thirteen years will have negative, and one year will have equal to the mean. Furthermore, the years 2041 and 2049 are expected to be the wettest years while years 2051 and 2064 will be driest years, whereas at Nefas Mewcha 12 years are expected to have positive anomaly, and 16 will be years of negative rainfall anomaly while two years will be years of normal rainfall anomaly (same as long term average of the study period). Moreover, years 2047 and 2053 are expected to be wettest years while the years 2042 and 2059 are expected to be the driest years in the study period. At Werota the model projected 12 years of positive, and 17 years of negative anomaly indicaing that there will be more years of low rainfall below the long term mean of the study period. At the same time the model predicted that the year 2047 will be the wettest years, and the years 248 and 2052 will be driest years of the study period. With regard to the CSIRO RCP 8.5, at Debre Tabor there will be equal below and above normal (long term average) years of rainfall where 15 years will have negative/ positive rainfall anomaly, whereas at Nefas Mewcha 13 years will have rainfall above the normal while 12 years will have negative anomaly with 5 years expected to have rainfall of the long term mean (normal). On the other hand, at Werota the model predicted more number of years (17) with positive anomaly above the long term mean and 12 years of rainfall below the mean.

Table 8. Projected *Kiremt* season rainfall anomalies of future mid-century at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (2040-2069).

Station	**Model**	**Scenarios**	**Positive Anomaly**	**Negative Anomaly**	**Neutral Anomaly**
Debre Tabor	CSIRO	RCP4.5	16	13	1
		RCP8.5	15	15	0
	MIROC	RCP4.5	15	14	1
		RCP8.5	15	15	0
Nefas Mewcha	CSIRO	RCP4.5	15	13	1
		RCP8.5	12	16	2
	MIROC	RCP4.5	13	12	5
		RCP8.5	14	15	1
Werota	CSIRO	RCP4.5	12	17	1
		RCP8.5	13	16	1
	MIROC	RCP4.5	12	15	3
		RCP8.5	13	15	2
Areal average	CSIRO	RCP4.5	14	15	1
		RCP8.5	13	16	1
	MIROC	RCP4.5	13	14	3
		RCP8.5	14	15	1

On the other hand, the MIROC under RCP4.5 predicted that there will be 15 and 14 years of above normal (positive anomaly) and below normal (negative anomaly) years of rainfall,

respectively at Debre Tabor, and conversely 14 and 15 years above normal (positive anomaly) and below normal (negative anomaly) years of rainfall, respectively at Nefas Mewcha. At Werota however, there will be more (16) years of positive anomaly and relatively less (13) years of negative anomaly (years of below normal) rainfall. Similarly under RCP8.5 the MIROC predicted equally 15 years of positive/ negative rainfall anomaly at Debre Tabor, whereas it predicted relatively more number of years with positive anomaly at Nefas Mewcha and Werota.
The more number of years predicted with negative anomaly at Werota by both the general circulation models under both emission scenarios could indicate the likely chance of occurrence of more number of years of rainfall less than the long term average of the study period.

4.1.2. Trends in projected mid-century rainfall

The trends of the future mid-century rainfall projected by CSIRO and MIROC models under RCP 4.5 and RCP8.5 (Table 12) varied among models and emission scenarios. Both the models under both the emission scenarios predicted tendency of consistently positive trends of total rainfall, SOS, EOS, LGP,NDD and Negative trends of NRD at Debre Tabor, whereas at Nefas Mewcha, both the models under both the emission scenarios predicted consistent tendency of positive trends of total rainfall and NRD, and conversely negative trends of EOS. At Werota however, both the models consistently predicted tendency of positive trends of NDD and conversely consistent negative trends of Total rainfall and NRD. On the other hand, at Nefas Mewcha the CSIRO under RCP4.5 predicted tendency of negative trends of SOS, EOS, NDD, NRD and conversely positive trends of total rainfall, LGP and NRD, whereas the CSIRO under RCP4.5 predicted tendency of negative trends of EOS, LGS and NDD and conversely positive trends of total rainfall, SOS and NRD (Table 12). Similarly the MIROC under RCP 4.5 predicted tendency of negative trends of SOS, EOS and NDD, and conversely positive trends of total rainfall, LGP and NRD, whereas the MIROC under RCP 8.5 predicted tendency positive trends for all parameters studied. At Werota, however, the CSIRO under RCP4.5 predicted tendency of negative trends of total rainfall, SOS, EOS, LGP and NRD, and conversely positive trends of NDD, whereas the CSIRO under RCP 8.5 predicted tendency of negative trends of total rainfall, LGP, and NRD, and conversely positive trends of SOS, EOS NDD. Similarly the MIROCS under RCP 4.5 predicted negative trends of total rainfall, EOS, LGP, and NRD, and conversely positive trends of SOS, and NDD whereas MIROC under RCP 8.5 predicted tendency of negative trends of total rainfall and NRD, and conversely positive trends of SOS, EOS, LGP, and NDD.

Table 9. Trends in projected future mid-century seasonal Kiremt rainfall characteristics, at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (2040-2069)

variables	Models and scenario	Debre Tabor		Nefas Mewcha		Werota		Areal Average	
		Z_{mk}	Slope	Z_{MK}	slope	Z_{MK}	slope	Z_{MK}	slope
Total rainfall	CSIRO-RCP4.5	1.50	8.40	1.14	2.95	-0.61	-2.54	0.29	1.02
	CSIRO-RCP8.5	0.96	6.74	1.21	3.88	-0.75	-2.95	0.68	1.63
	MIROC-RCP4.5	1.32	7.55	1.46	4.11	-1.03	-4.88	0.07	0.07
	MIROC-RCP8.5	1.39	8.06	1.18	3.63	-1.00	-5.10	0.00	0.13
SOS	CSIRO-RCP4.5	2.22^{*}	0.50	-0.62	-0.33	-0.23	-0.09	0.29	0.12
	CSIRO-RCP8.5	1.91	0.50	0.23	0.10	0.58	0.25	0.73	0.20
	MIROC-RCP4.5	1.97^{*}	0.50	-0.42	-0.22	0.71	0.27	0.79	0.30

	MIROC-RCP8.5	1.99*	0.44	1.88*	0.44	1.98*	0.44	0.32	0.10
EOS	CSIRO-RCP4.5	0.65	0.15	-0.48	-0.02	-1.47	-0.16	0.34	0.11
	CSIRO-RCP8.5	0.58	0.14	-0.48	-0.02	-1.25	-0.04	0.86	0.300
	MIROC-RCP4.5	0.65	0.20	-0.48	-0.02	-0.01	-0.01	-0.40	-0.10
	MIROC-RCP8.5	0.63	0.15	0.61	-0.14	-0.63	-0.30	-0.40	-0.10
LGS	CSIRO-RCP4.5	0.25	0.17	0.50	-0.21	-0.82	-0.66	-0.00	-0.00
	CSIRO-RCP8.5	0.43	0.25	-0.57	-0.26	-1.24	-0.87	-1.10	-0.20
	MIROC-RCP4.5	0.23	0.11	0.23	0.16	-1.03	-0.80	-1.2	-0.40
	MIROC-RCP8.5	0.43	0.30	0.42	0.30	0.42	0.30	-1.00	-0.20
NRD	CSIRO-RCP4.5	-0.36	-0.06	1.99*	0.38	-2.04*	-0.36	0.00	0.00
	CSIRO-RCP8.5	-0.25	-0.01	1.90	0.38	-1.84	-0.38	0.11	0.02
	MIROC-RCP4.5	-0.13	-0.01	1.90	0.38	-1.81	-0.30	0.16	0.02
	MIROC-RCP8.5	-0.02	-0.01	1.86	0.36	-1.79	-0.31	0.23	0.00
NDD	CSIRO-RCP4.5	0.36	0.06	-1.89	-0.37	1.84	0.37	0.00	0.00
	CSIRO-RCP8.5	0.25	0.00	-1.89	-0.38	1.80	0.30	-0.180	-.020
	MIROC-RCP4.5	0.13	0.00	-1.86	-0.36	1.78	0.30	-0.20	-0.00
	MIROC-RCP8.5	0.02	0.00	-0.01	-0.01	0.01	0.00	-0.20	-0.00

SOS is start season; EOS is end of season and LGS is length of growing season; NRD is number of rainy and NDD is number of dry days, Z_{mk} is Man-kendal trend test, slope is Sen's estimator of rate of change/year, * is significant trends at 5% probability level.

However, the predicted trends of the future rainfall were significant only for the increasing SOS as predicted by CSIRO under RCP 4.5, by MIROC under RCP 4.5 and by MIROC under RCP 4.8 at Debre Tabor; for the increasing SOS predicted by MIROC under RCP8.5 and for NRD as predicted by CSIRO under RCP4.5 at Nefas Mewcha, and for the increasing SOS as predicted by MIROC under RCP8.5 and for the decreasing NRD as predicted by CSIRO under RCP4.5.

This shows that most of the studied rainfall variables will not show significant future trends, and the significant trends are not systematic though models agreed on expected significant trends of SOS at Debre Tabor. The result could thus be an indication of mire variable trends of the future rainfall scenario which corroborates previous reports of Zeray et al. (2007), Yimer et al. (2009), Tamiru (2011) and Ayalew et al. (2012) indifferent parts of the country.

4.1.3. Projected mid-century temperature variability

Analysis of the projected climate variability in terms of seasonal mean (Mean Tmp), mean of the maximum (TMAXmean) and mean of the minimum (TMINmean were less variable between the two models and the emission scenarios across weather stations(Table 11). Nevertheless, the variability predictions were more variable among temperature variables / parameters. Based on the coefficient of variability (CV), both models under both emission scenarios agreed that the computed values of CV were less than 20 for the Mean Tmp, TMAXmean, across all weather stations indicating less variable condition for the study period.(Table 11).

With regard to predictability, results were variable among models and emission scenarios, weather stations and study variables/ parameters. The computed values of the standard deviations (SD) were consistently less than 10 for the TMAXmean, across models, emission scenarios and weather stations indicating high stability and hence more predictability of the future mid- century temperature. Conversely, the SD values were variable across models/ emission scenarios/ weather stations for the Mean Tmp and TMINmean. The seasonal Mean Tmp was predicted by CSIRO-RCP4.5 as highly stable at Nefas Mewcha while the rest of the model emission scenarios predicted very high stability at all weather stations.

Table 10. Summary statistics of predicted seasonal Mean Tmp, Tmax and TMIN at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gonder Zone, Amhara National Regional State Ethiopia (2040-2069).

variable		Debre Tabor						Nefas Mewcha						Werota						Zonal average					
		Maximum	Mean	Minimum	Median	CV%	SD	Maximum	Mean	Minimum	Median	CV%	SD	Maximum	Mean	Minimum	Median	CV%	SD	Maximum	Mean	Minimum	Median	CV%	SD
Mean Tmp	CSIRO-RCP4.5	17	16	15	16	2	0	15	14	13	14	3	0	24	21	17	21	7	2	19	17	15	17	4	1
	CSIRO-RCP8.5	19	18	17	18	2	0	16	15	14	15	2	16	24	21	18	22	7	1	20	18	16	18	4	6
	MIROC-RCP4.5	19	18	17	18	2	0	14	14	13	14	3	0	24	21	17	21	7	2	19	18	16	18	4	1
	MIROC-RCP8.5	19	18	17	18	2	0	16	15	14	15	2	0	23	20	16	20	8	2	19	18	16	18	4	1
TMAX mean	CSIRO-RCP4.5	23	21	19	21	4	1	19	18	17	18	3	1	27	29	25	27	1	4	23	23	20	22	3	2
	CSIRO-RCP8.5	25	23	21	23	3	1	19	18	17	18	3	1	28	29	26	28	1	3	24	23	21	23	2	2
	MIROC-RCP4.5	25	23	21	23	3	1	19	18	17	18	3	1	27	29	25	27	1	4	24	23	21	23	2	2
	MIROC-RCP8.5	25	23	21	23	3	1	21	20	19	20	3	1	26	28	24	26	1	4	24	24	21	23	2	2
TMIN mean	CSIRO-RCP4.5	12	11	10	11	3	0	10	9	8	9	6	1	14	20	7	15	3	19	12	13	8	12	4	7
	CSIRO-RCP8.5	14	13	12	13	3	0	10	9	8	9	6	1	15	20	8	15	3	18	13	14	9	12	4	6
	MIROC-RCP4.5	14	13	12	13	3	0	10	9	8	9	6	1	14	20	7	15	3	19	13	14	9	12	4	7
	MIROC-RCP8.5	14	13	12	13	3	0	11	10	9	10	5	1	14	19	7	14	3	20	13	14	9	12	4	7

4.1.4. Trends of projected mid-century temperature

As is evident from Table 15 the projected mid-century temperature variables showed spatial variability of increasing significantly in Maximum and minimum temperature whereas non significantly increasing trend in the mean temperature trends for the study area over the study period. From the tables it is apparent that at Debre Tabor, temperatures predicted by both the CSIRO and the MIROC models under both the RCP 4.5 and the RCP 8.5 scenarios appeared consistent with tendency of positive trends of Mann kendal trend test of seasonal Mean Tmp, TMAX mean and TMIN mean. At Nefas Mewcha, the Mann kendal trend test (Table 15) showed that the trends predicted by both the CSIRO and the MIROC models under both the RCP 4.5 and the RCP8.5 emission scenarios appeared consistent with tendency of positive trends for Mean Tmp, TMAX mean, and TMIN mean. Also at Werota, the trends predicted by both the CSIRO and the MIROC models under both the emission scenarios appeared consistent with tendency of increasing trends for Mean Tmp, and TMIN mean and conversely negative trends of TMAXmean (Table 12).

Table 12. Trends in projected future mid-century seasonal MeanTmp, Tmax, and TMIN variables at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (2040-2069)

variables	**Models and scenario**	**Weather Stations**							
		Debre Tabor		**Nefas Mewcha**		**Werota**		**Zonal Average**	
		Z_{mk}	**Slope**	**Z_{mk}**	**Slope**	**Z_{mk}**	**Slope**	**Z_{mk}**	**Slope**
Mean Tmp	CSIRO-RCP4.5	0.64	0.01	0.11	0.00	3.28*	0.08	3.56*	0.02
	CSIRO-RCP8.5	0.64	0.00	0.11	0.00	3.35*	0.08	3.35*	0.02
	MIROC-RCP4.5	0.64	0.00	0.11	0.00	3.23*	0.08	3.38*	0.02
	MIROC-RCP8.5	0.64	0.01	0.11	0.00	3.35*	0.08	3.38*	0.02
TMAXmean	CSIRO-RCP4.5	1.18	0.02	0.25	0.00	-0.41	-0.01	1.5	0.01
	CSIRO-RCP8.5	1.19	0.02	0.25	0.00	-0.32	-0.01	1.48	0.0
	MIROC-RCP4.5	1.18	0.02	0.29	0.00	-0.32	-0.01	1.49	0.01
	MIROC-RCP8.5	1.18	0.20	0.27	0.00	-0.32	-0.01	1.49	0.01
TMINmean	CSIRO-RCP4.5	0.04	0.00	0.12	0.00	3.64*	0.16	3.9*	0.05
	CSIRO-RCP8.5	0.00	0.00	0.12	0.00	3.39*	0.16	3.92*	0.05
	MIROC-RCP4.5	0.04	0.00	0.14	0.00	3.53*	0.16	3.92*	0.05
	MIROC-RCP8.5	0.04	0.00	0.14	0.00	3.39*	0.16	3.92*	0.05

The results of the present study showed that for the study period maximum and minimum temperatures are expected to significantly increase in the upcoming mid-century. Models/emission scenarios agreement on the significant increase or decrease of trends of some variables could be an indication of the more likelihood of occurrence of such trends. Similar variable trends were also reported by Hadgu et al (2014) over the Northern Ethiopia.

4.5. Implication of Projected Climate on Future mid-century Crop Production

The impacts of climate on crop production are closely related to the spatial and temporal distribution and variability of elements of rainfall and temperature. As the results of the present study indicated, observed rainfall and temperature variables of agricultural significance have shown complex and variable spatial and temporal patterns in the South Gondar zone of the Amhara National Regional State, where this study was conducted. Investigation of interconnections of these variables with zonal level major crops production, productivity and area under production also revealed complex interplay between crop production and climate variables. Each of which has its own positive or negative or neural individualistic effect which in reality is difficult to single out as the interplay is overwhelming. The observed increase in yield of teff, barley and wheat could thus be partly be attributable to the positive play of rainfall and temperature variables by increasing productivity and expansion of area of production. The question, however, is that could the future climate remains supportive of the current pace of crop production or may it be an ultimatum of it?

Projections of future mid-century climate showed variable scenarios in time and space in the zone. However, on average at zonal level, projections revealed that an increase in the amount of rainfall by over 60 mm, number of rainy days by 0-1 days, and increase in mean temperatures by 2.1-2.6^{o}C, mean maximum temperatures by 2.5-3.6 ^{o}C, mean minimum temperatures by 1.4-2.5 ^{o}C, diurnal range of temperatures by 0.0-.0.2 ^{o}C, maximum of the minimum temperatures by 0.4-1.5^{o}C, minimum of the maximum temperatures by 0.3-1.7 ^{o}C, minimum of the minimum temperatures by 2.5-3.2 ^{o}C, and conversely increase in early onset of season by 1-5 days, late end of season by 9-12 days, length of growing period by 11-15 days, and decrease in number of warm days by 0.6-1.2 days, number of warm nights by 0-1.3 days, number of cool days by 0.5-1.7 days, number of cool nights by 0-0.8 days and maximum of the daily maximum temperatures by 0-1.2 ^{o}C over the historical base period, signaling variable scenarios and associated opportunities and challenges ahead to come.

The predicted scenarios of increase in length of growing days due to the early on set and late cessation of rainfall could be taken as an opportunity for extended availability of soil moisture. Availability of soil moisture for extended period could help the crops grow well, synthesis more assimilates, accumulate more biomass, and mobilize towards reproductive development and grain filling for larger seed size and hence more grain yield.

Such opportunities, however, might be negatively countered by the predicted shortfall in amount of rainfall of the season which when coupled with un increased number of rainy days could result in reduced amount of moisture with variable distribution. Furthermore, the projected increase in mean temperatures above the current base level will increase atmospheric warming and causes increased evaporation of the scanty soil moisture. The warming scenario may also cause heat stress to plants, hasten physiological processes, increase respiration and induce early maturity with reduced biomass and shriveled grain yield.

Moreover, the increased warming may result in relocation of currently adapted area of production and substitution of crops. The warming scenario may open up new area of production for teff -currently dominating the warmer low and mid altitude areas- in the cooler higher altitude currently dominated by barley. On the other hand, barley may lose substantial areas of its current production due to lack of or limited areas available to move in to above the current altitudinal limit, and it may be replaced by teff and /or wheat. Hence upcoming mid- century crop production could be characterized by reduced productivity, lose or gain of area of production and low yield.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary and Conclusion

Information on the seasonal climate (rainfall and temperature) variability and trends is very important for planning and water management practices in rain fed agriculture of Ethiopia where more than 85% of the population is dependent on agriculture. In response to this, in the present study climate variability and its implication to crop production in the cause of South Gondar Zone, Amhara National Regional State, Ethiopia was conducted to investigate the variability and trends of future climate in terms of various rainfall and temperature parameters which are agricultural significance for major crops (teff, barley and wheat) of the zone and to discussed implications of the future climate on future crop production.

Accordingly projected mid- Century (2040-2069) rainfall and temperature data downscaled using the CSIRO Mk 3.6.0, and the MIROC 5 climatic models under the RCP 4.5 and RCP 8. 5 emission scenarios and analyzed for temporal variability (CV, SD, maximum, minimum and mean among others) and trends. The climate variables of seasonal kiremt rainfall total, start of season (SOS), end of season (EOS), length of growing period (LGS), number of rainy days (NRD), number of dry days (NDD) were analyzed using various statistical packages**.**

The results showed that the *kiremt* season rainfall was spatially decreasing from western to the eastern part of the Zone. The start of the rainy season was moderately variable and showed tendency of becoming late while end of season was less variable and more stable. On the other hand the length of the *kiremt* growing season was moderate to highly variable with varying probability of occurrence of dry spells and number of dry days. The number of rainy days also showed comparable variability among weather stations with rainfall amount at Werota. The observed trends were also non -significant for all studied rainfall variables at all weather stations and the Zonal average as well.

Similarly, among temperature variables, the seasonal mean temperature (Mean Tmp), mean maximum (TMAXmean), mean minimum (TMINmean), diurnal range of temperatures (DTR), showed more variability at Werota when compared with the others in the study area. Moreover, the observed trends of the temperature variables revealed variability with the majority showing increasing trends. The trends however, were significant only for few with majority being at Werota and are spatially non- systematic.

Prediction of future mid -century climate also showed high variability of rainfall start of season and conversely less or moderately variable end of season, length of growing season, number of rainy days and number of dry days. Similarly trends were variable and incoherently significant only for very few variables, and also lack spatial consistence in direction of changes over the base period.

Among temperature variables, the seasonal mean temperatures mean seasonal maximum, and showed less variable condition for the study period . Models generally agree that most significant trends are not spatially coherent. Nevertheless, most of the studied temperature variables showed increased warming over the base period.

Nevertheless, the predicted increase in future mid- century warming may result in crop area relocation and yield reduction.

5.2. Recommendation

Based on result of the present study, to address the current and foresee problems of climate variability and change, the following recommendations could be forwarded: to complement the present findings, there is a need to conduct controlled experiments on simulated moisture and temperature gradients to exploit varietal differences in crops response to climate change and variability. There is also a need to develop and diversify heat stress tolerant and moisture efficient crop varieties to combat anticipated crop area relocation and yield reductions.

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