



Research Paper

Analysis of climate change under future climate scenarios in Bale highlands, Southeastern Ethiopia

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ABSTRACT

The analysis of climate is very local in nature, hence a local level and specific understanding is extremely important. With this understanding, a study was conducted in Bale highlands of southeastern Ethiopia to analyze climate change under future climate scenarios. Historical climate data (1984-2016) and future climate data (2020-2095) downscaled using the ensemble of all GCMs, were analyzed to understand the local level climate change. The analysis showed that rainfall and temperature were highly variable in highlands of southeastern Ethiopia through time slices of 2030's, 2050's and 2080's under both RCP4.5 and RCP8.5 scenarios. The result of historical data analysis showed that, the seasonal kiremt rain was increased by 6.1 mm/yr at Sinana station and 2.9 mm/yr at Robe station. The results of this study showed that future projected seasonal rainfall total of belg was increased by 46.0 and -50.4% in 2030's, 33.8 and 39.7% 2050's, 59.2 and 39.4% 2080's under both scenarios at Sinana station. Similarly, it was increased by 99.7 and 84.9% in 2030's, 76.3 and 88.7% in 2050's, 90.4 and 85.6% in 2080's under both scenarios at Robe station. It was observed that in the upcoming century, the amount of belg rainfall is expected to increase than that of kiremt rainfall at both stations. The historical data mean, maximum and minimum temperatures trend at Sinana and Robe stations showed significant increases. Future projected air temperature change was investigated and it was shown that the mean air temperature increased by 1.2°C at Sinana and 1.8°C at Robe in 2030's under RCP4.5 scenario. Additionally, the mean air temperature increased by 1.7 and 2.2°C at Sinana and 2.2 and 2.7°C at Robe in 2050's under RCP4.5 and RCP8.5 respectively. Similarly, the mean air temperature was significantly increased by 2.1 and 2.9°C at Sinana, while 2.7 and 4.0°C at Robe in 2080's under both scenarios. Therefore, rainfall and temperature had a severe change that justifies climate change and global warming need for site specific study.

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INTRODUCTION

Globally, temperature is increasing and the amount and distribution of rainfall is being altered differently from one region to another (IPCC, 2014a). Scientific assessment reports proved that global average temperature would rise

between 1.4 and 5.8°C by 2100 with the doubling of the CO₂ concentration in the atmosphere (Cubash et al., 2001). Temperature is the main climatic factor contributing to high evaporative demand and the corresponding crop

water requirement that exacerbate the risks of rainfall related features on crop yields. The impacts of increased temperature from global warming and changes in rainfall patterns resulting from climate change are expected to reduce agricultural production and put further pressure on marginal land (Beddington et al., 2012; Valizadeh et al., 2013). The seasonal climate variability of Ethiopia, particularly rainfall, is influenced by weather systems of various scales; from meso scales, to the large scale (NMSA, 1996). The present study intends to analyze the future climate change in the Bale highlands of South Eastern Ethiopia. The findings of this study can be used as inputs for researchers, extension experts and decision makers to enable the selection of suitable crops/varieties, to enable policy makers to get prepared for negative impacts on their livelihood and can serve as reference/baseline for further studies. Hence, this study is expected to fill the knowledge gap on the understanding of future climate in Bale highlands under changing climate. Based on the skill of the designed models, the local development partners, as well as farmers can utilize the information as primary input in designing early stage protective measure and minimize the adverse effect of climate-related risks on their activities. Thus, the present study was initiated with the objective of analyzing climate change under future climate scenarios in bale highlands, southeastern Ethiopia

MATERIALS AND METHODS

General description of the study area

The study were carried out at Sinana Agricultural Research Center and Robe stations Sinana District, which is a part of highlands of Bale Zone, Southeastern Ethiopia located at 6° 50' N-7°17' N and 40° 06' E-40°25' E, 430 km southeast of Addis Ababa. Altitude ranges from 1700 to 3100 m above sea level (m.a.s.l).

Historical climate data

The 33 years daily maximum and minimum temperatures, rainfall, as well as sunshine hour duration data were obtained from Sinana Agricultural Research Center (SARC) and National Meteorological Agency (NMA) of Ethiopia. The daily observed climate data were checked for quality and missing values, and patched using Markov chain model of INSTAT v.3.37 software package. The areas are characterized by a bimodal rainfall pattern with total mean annual rainfall of 905.13 and 812.4 mm for Sinana and Robe, respectively. As shown in [Figures 1 and 2 of the Appendix](#), the area has bimodal rainfall distribution, that is,

Belg season (short rainy season) in the months of February to May and kiremt (the main rainfall season) extending from June to September. Belg receives about 17.1 to 130 mm at Sinana and 19.5 to 106.5 mm at Robe, whereas Kiremt receives 10.5 to 160 mm at Sinana and 64.6 to 120 mm at Robe. The mean minimum, maximum and average of annual temperature of the Sinana is 9.6, 21.3 and 15.5°C, while for Robe is 8.1, 21.6, and 14.9°C, respectively. The average air temperature in the Belg season (February, March, April and May) was 15.95°C at Sinana and 14.9°C at Robe stations, whereas the main season which is called Kiremt season, the average air temperatures was about 15.6°C for both stations.

Projection of future climate data

Climate change scenarios were developed to assess the future impacts of climate change on crop productivity in the Bale highlands. MarkSim is currently used to downscale outputs from GCMs and generate daily future climate data at a specific site. Future climate over the Bale highlands was downscaled at Sinana and Robe stations from ensemble of all 17 global GCMs and representative concentration pathways (RCP) for time period centered around 2030's, 2050's and 2080's predictors. The ensembles of all 17 models, a new feature of the updated GCM model, were used for impact analysis during climate change and variability analysis as well. Representative Concentration Pathways (RCPs) new scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) in Fifth Assessment Report (AR5) were used for emission scenario. To predict future precipitation and temperature, the medium range emission scenario (RCP4.5) and very high emission scenario (RCP8.5) were used in the present study using a web based software tool MarkSim online software web version for IPCC AR5 data (CMIP5). MarkSim GCM is a spatially explicit daily weather generator that uses third order Markov chain climate simulator and has been found suitable for tropical countries like Ethiopia (Jones and Thornton, 2013). Moreover, it does not depend on the long term climate data and does not need recalibration, as it is already calibrated (Jones and Thornton, 2003). MarkSim GCMs require geographical coordinates and station name to downscale and generate daily future data of a given site. The Model is linked with Google earth to indicate the place which is being dealt with and has options to use different types of MarkSim GCMs. In this study, the average ensemble of all the GCMs and scenarios of RCPs (RCP4.5 and RCP8.5) were downscaled to generate the climate variables from 2020-2095 for Sinana and Robe stations. As a final product of downscaling ensembles of all GCM, daily climate data were generated for this study. The downscaled future daily

ensembles of all GCMs climate data were used to examine the monthly patterns and general trend of annual rainfall, seasonal rainfall, and average annual and seasonal minimum and maximum temperatures of the study areas for future (2020-2090) periods by averaging the independent ensemble data. Based on the analysis plan of Sinana and Robe, future climate extreme indices were analyzed. In this regards, output data of two RCP emission scenarios (RCP4.5 and RCP8.5) for ensembles of all GCM output were used to study the future trend of the climate extreme indices.

RESULTS AND DISCUSSION

Future projected of annual, seasonal and monthly rainfall characterization

Mean annual rainfall

As compared with the baseline period, the annual rainfall totals were expected to increase by ensembles of all GCMs under both RCP4.5 and RCP8.5 emission scenarios predicted for both locations except near century (2030's) under RCP8.5 at Sinana station. Future prediction of annual rainfall totals indicated that significant increasing trend was expected at the Robe station as compared with baseline data for observed period (Figure 1).

For projected climate analysis, the rainfall was increased by 18.8% at Sinana and 33.06% at Robe in near century (2030's) under RCP4.5 scenario. However, under RCP8.5 scenario, it was decreased by -56.95% at Sinana and increased by 30.67 % at Robe. This means that there were high amount of rainfall expectation in the near century (2030's) under RCP4.5 than RCP8.5, whereas, in the mid century (2050's), it deviated (increased) from the baseline average annual rainfall by 15.2% under RCP4.5 and 18.4% under RCP8.5 at Sinana. Similarly, it was increased from the baseline average annual rainfall by 29.58% under RCP4.5 and 34.56% under RCP8.5 at Robe. By the end of the century (2080's), the annual rainfall was increased by 20.3% at Sinana and 32.64% at Robe under RCP4.5 and by 15.0% at Sinana and 31.15% Robe under RCP8.5 scenario. Based on analysis using all ensembles GCMs, there were increases in trends of future rainfall totals at Sinana and Robe stations with models projecting increases in rainfall. This result showed that, the increase in rainfall amount in the study area was more conducive for rain-fed agricultural practice, especially for wheat production. The study also showed that in the near century (2030's), mid century (2050's) and end century (2080's) periods, the rainfall deviation from baseline was approximately the same and had the same impact on wheat production in both locations.

Overall, as compared with the base period (1984-2016), the change in annual rainfall total in Sinana and Robe areas was significant in almost all time slices of 2030's, 2050's and 2080's under RCP4.5 and RCP8.5 scenarios. Therefore, crop production under all time slices were better in the study sites; however, much water logging was expected with high amount of rainfall received for the future due to soil condition in the study area classified under Phaeozems, Cambisols and Vertisols. This might negatively affect agriculturally important rainfall features, casing productivity to diminish.

Seasonal rainfall totals

Seasonal changes of projected rainfall showed increasing trend of kiremt (JJAS) rainfall totals in all time slices for both locations (Table 1). The kiremt rainfall total was increased for the scenarios considered in this study. However, the magnitude was higher for the mid concentration (RCP8.5) as compared with other concentrations of the scenarios, while the change in kiremt rainfall totals decreased during the near century (2030's) under RCP8.5 scenario at Sinana. However, in near century (2030's), it was decreased under RCP8.5 scenarios significantly. On the other hand, the results showed that an increasing trend of Belg (FMAM) rainfall totals is expected in the Sinana area (Table 1). Similarly, it was shown that the average seasonal rainfall total of Belg (FMAM) increased by 46.0% and decreased -50.4% in near century (2030's), 33.8 and 39.7% in mid-century (2050's), 59.2 and 39.4% at end century (2080's) under both scenarios at Sinana station. Future projected seasonal rainfall total of Belg (FMAM) increased by 99.7 and 84.9% in near century (2030's), 76.3 and 88.7% in mid-century (2050's), 90.4 and 85.6% at end century (2080's) under both scenarios at Robe station. As shown in this study, in the upcoming century, it was expected high rate of increase in the amount of Belg rainfall (FMAM) than that of Kiremt rainfall (JJAS) for Sinana and Robe areas, whereas more was expected at Robe station. The study also showed that, the Bega rainfall totals (ONDJ) were significantly decreased in near (2030's), mid (2050's) and end century under both scenarios. The rate of decrease in the Bega rainfall total (ONDJ) was by -30.5 and -21.6% in near (2030s), -21.2 and -28.7% in mid (2050's) and -69.1 and -30.8% at end century (2080's) at Sinana and by -39.2 and -36.6% in near (2030's), -29.9 and -37.8% in mid (2050's) and -31.7 and -37.5% at end century (2080's) at Robe under RCP4.5 and RCP8.5 scenarios, respectively.

When compared with the baselines, the kiremt rainfall total was likely to increase and could reach up to 449.2 and 369.1 mm under RCP4.5 and RCP8.5 scenarios, respectively

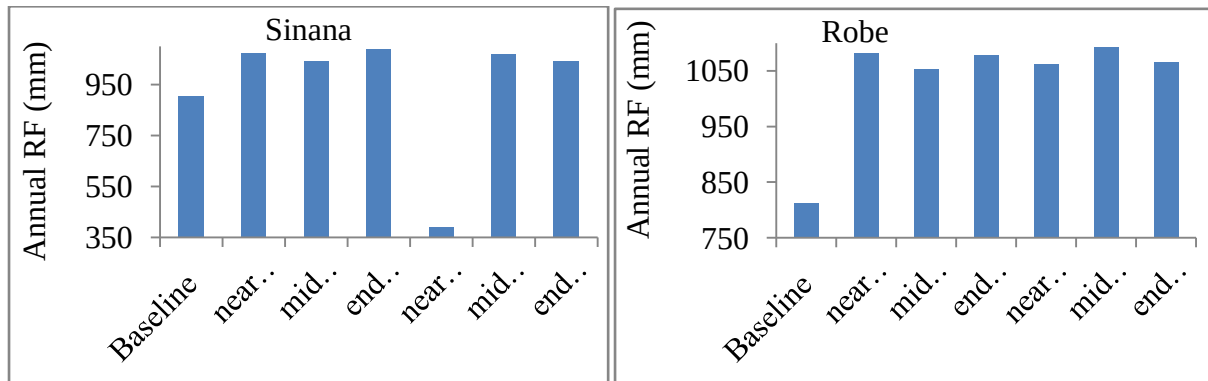


Figure 1: Bar graph of comparison of projected average annual rainfall with the baseline under RCP4.5 and RCP8.5 by ensembles of all GCM models.

Table 1: Future projected change in average seasonal rainfall total (%) from the baseline in different time slices under RCP4.5 and RCP8.5 scenarios.

Sinana station			
	JJAS	FMAM	ONDJ
Baseline	402.5	339.0	163.7
RCP4.5near century	+15.9	+46.0	-30.5
RCP4.5 mid century	+14.3	+33.8	-21.2
RCP4.5 end century	+4.6	+59.2	-21.6
RCP8.5near century	-57.6	-50.4	-69.1
RCP8.5 mid century	+19.6	+39.7	-28.7
RCP8.5 end century	+13.1	+39.4	-30.8

Robe station			
	JJAS	FMAM	ONDJ
Baseline	367.3	259.1	186.0
RCP4.5near century	+22.6	+99.7	-39.2
RCP4.5 mid century	+26.7	+76.3	-29.9
RCP4.5 end century	+24.5	+90.4	-31.7
RCP8.5near century	+26.5	+84.9	-36.6
RCP8.5 mid century	+33.0	+88.7	-37.8
RCP8.5 end century	+27.4	+85.7	-37.5

at Sinana. Similarly, the kiremt rainfall total at Robe area was expected to increase up to 457.7 and 473.7 mm under RCP4.5 and RCP8.5 scenarios. However, the Belg rainfall totals (FMAM) could reach about 496 mm at Sinana and 489.2 mm at Robe under RCP4.5 scenario and then decline to 371.5 mm at Sinana and 483 mm at Robe under RCP8.5 scenario. Furthermore, it could also be seen from [Figure 2](#) that Bega rainfall totals (ONDJ) were higher under RCP4.5 scenario than under RCP8.5 scenario, while baseline rainfall totals were the highest for both locations. The increasing

trend of seasonal rainfall over the Sinana in the future might have a positive impact on agricultural practices; especially for crop production due to enough rainfall expected in future climate projection output during Belg season. Bale highlands were characterized by bimodal rainfall forming two wheat growing seasons in a year. The two seasons were locally named at the time of crop harvest. The main cropping season locally called Bona (extends from July to December) and the other cropping season called Gana (extends from February to June). Crop growing

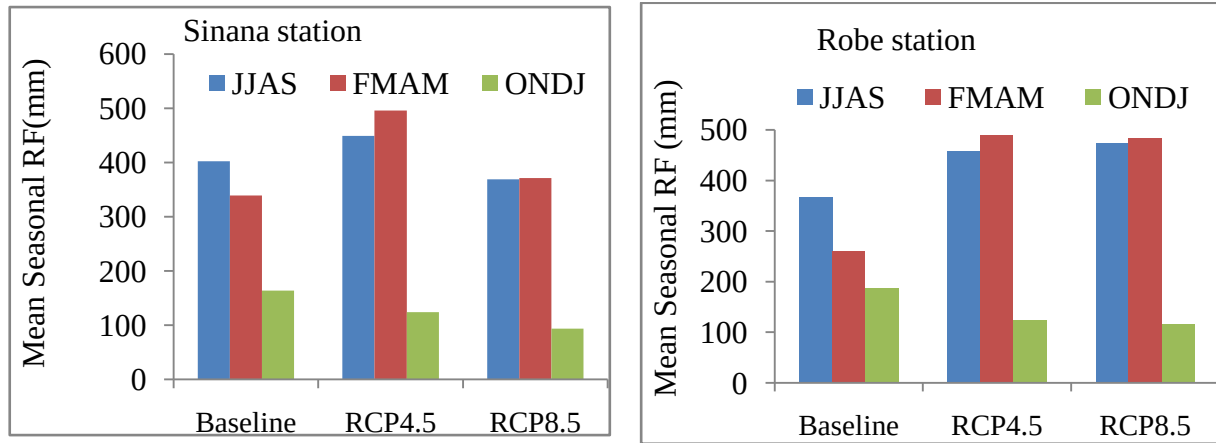


Figure 2: Comparison of projected average seasonal rainfall with the baseline under RCPs.

during Bona season might had negative impact on agricultural practices due to expected decreasing rainfall amount and increasing temperature for future climate projection at Sinana and Robe stations in Sinana district.

Mean monthly rainfall distribution

The projected mean monthly rainfall distribution at all time slices with the baseline period (1984-2016) under different scenarios in Sinana and Robe areas is shown in the **Figure 3**. Thus, the result showed that, in most cases, future rainfall increased considerably during the months of March to December at Sinana and March to July at Robe when compared with the baseline period. From historical data, the highest mean monthly rainfalls recorded was in the month of May and September at Sinana and Robe stations. In general, in the upcoming century, we expect high amount of Kiremt rainfall (JJAS) and Belg rainfall (FMAM) at Sinana and Robe in all time slices under both scenarios. This analysis indicated that, average rainfall in the area was observed in the future in Belg (FMAM) season than in Kiremt (JJAS) season at Sinana and Robe stations. Seasonal shifting of main rainy season (Kiremt) was expected in the future climate projection at both locations. This result is in agreement with what IPCC predicted for African climate as there was shifted of seasonal and monthly rainfall (IPCC, 2007).

Future temperature projection

Mean annual minimum temperature

Projected mean minimum temperature increased in all time

slices (2030's, 2050's and 2080's) by ensembles of all GCMs under both RCP4.5 and RCP8.5 scenarios. The historical analysis indicated that the annual mean of minimum temperature at Sinana was 9.6°C. When compared the baseline values with projected for all time slices, an increase by 0.1, 0.6, and 1.1°C was expected in near century (2030's), mid century (2050's) and end century (2080's) under RCP4.5 scenario. Also, the present study showed that an increase in mean annual minimum temperature values by 0.3, 1.2 and 2.6°C in near century (2030's), mid century (2050's) and end century (2080's) under RCP8.5 scenario respectively at Sinana. Similarly, for Robe area, the annual mean of minimum temperature historically was 8.1°C. When compared the baseline values with projected for all time slices, an increase by 1.6, 2.1 and 2.5°C was expected in near century (2030's), mid century (2050's) and end century (2080's) under RCP4.5 scenario (**Figure 4**). Also, it was shown an increase in mean annual minimum temperature values by 1.8, 2.6 and 4.1°C in near century (2030's), mid century (2050's) and end century (2080's) under RCP8.5 scenario respectively at Robe. The mean minimum temperature was increased significantly by 2.6°C at Sinana and 4.1°C at Robe in end century (2080's) under RCP8.5 scenario which was the highest increment of the expected century. This condition might be risk for production of wheat through enhancement of photosynthesis with the respective amount of average rainfall decreasing the expected yield in the future scenario.

Mean monthly minimum temperature

Mean monthly minimum baseline and projected minimum temperature for Sinana and Robe showed an increase in all

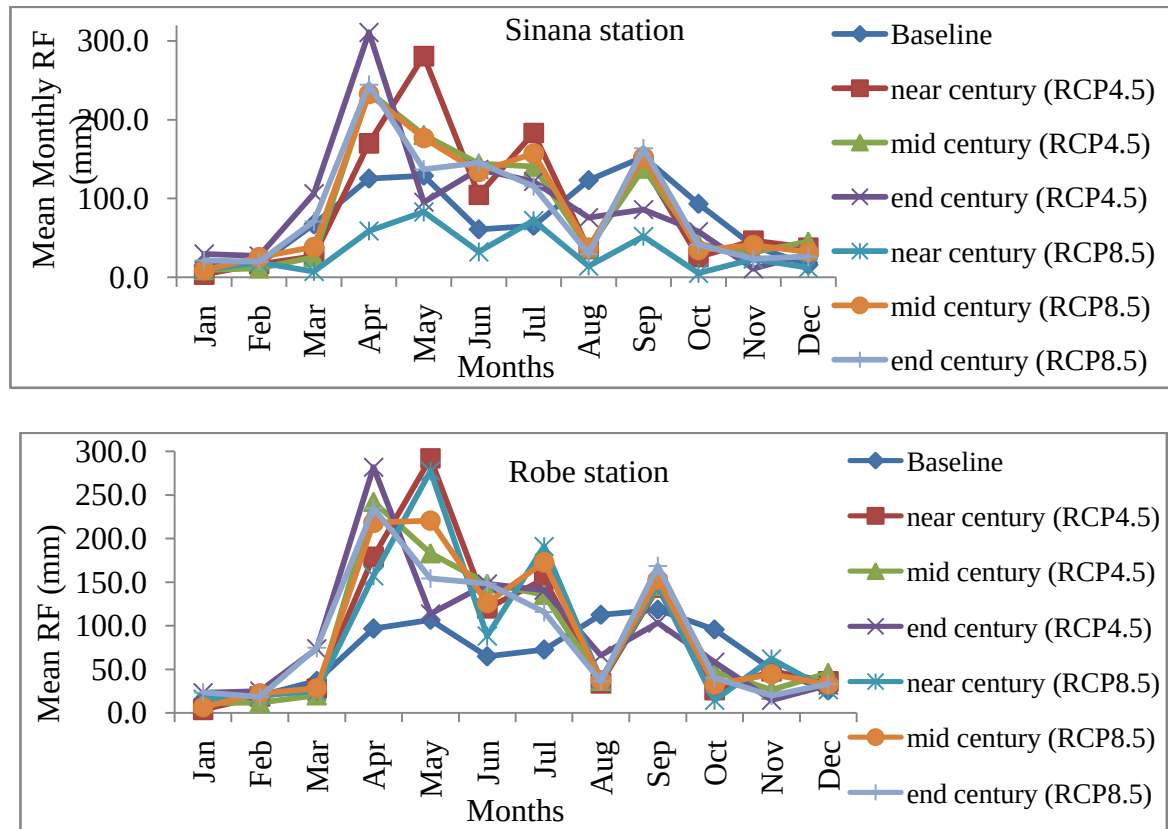


Figure 3: Comparison of observed mean monthly rainfall baseline data with all ensembles of GCM models predicted rainfall under different scenarios.

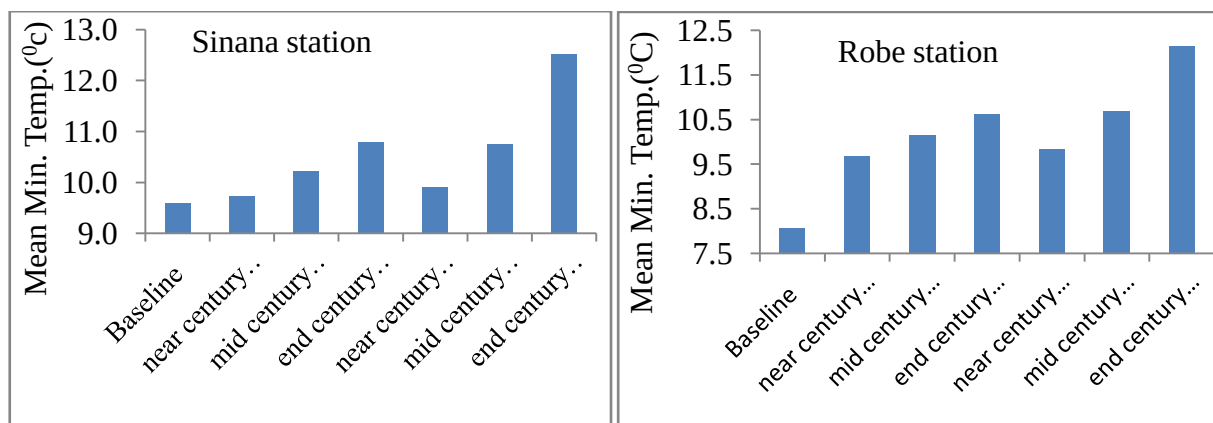


Figure 4: Model projected and baseline annual mean minimum temperature by all ensembles of GCM output under RCP4.5 and RCP8.5 scenarios.

time slices in some months (March to October) except a decrease in August for near century (2030's) and mid century (2050's) under both scenarios, while decrease was

observed in the rest of the months. **Figure 5** shows that the mean minimum temperature was increased significantly at end of the century (2080's) under RCP8.5 scenario as

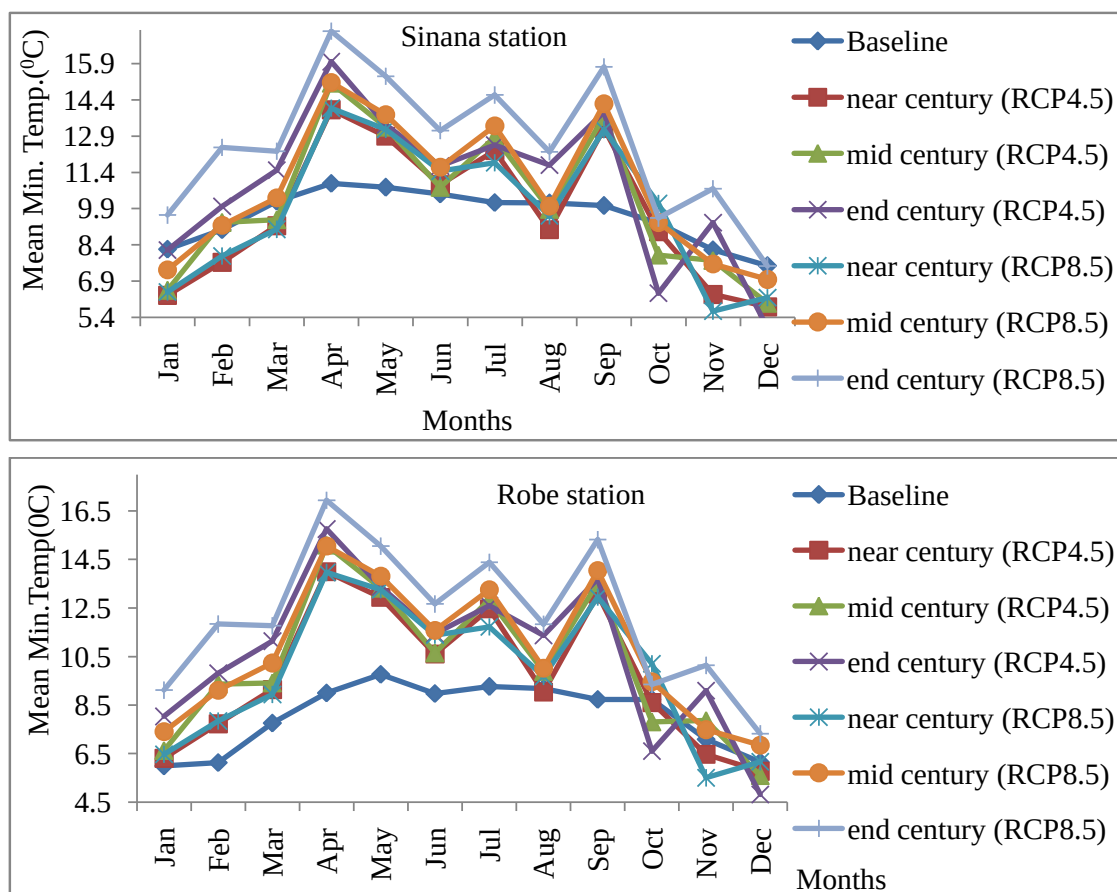


Figure 5: Model projected and baseline mean monthly minimum temperature by all ensembles of GCM output under RCP4.5 and RCP8.5 scenarios.

compared with other slices and baseline. The projected results showed that in the cropping season, the mean monthly temperature was significantly increased, especially at the end of the century (2080's) under RCP8.5 scenario. Moreover, the mean minimum temperature increased to 17.2 and 16.9°C in April which was differed from the baselines mean maximum temperature of 10.9 and 9.0°C registered in same month at Sinana and Robe stations, respectively. Crop productivity might be difficult in this period, and decrease in yield due to high temperature could increase the photosynthesis process up to maximum required for temperature. The decreasing rainfall amount in the cropping season was expected in upcoming century at Sinana and Robe areas. On the other hands, in future agricultural practices, drought resistance variety should be developed by researcher, especially breeders.

Mean annual maximum temperature

Mean annual maximum temperature increased with the

emission scenarios. The mean maximum temperature over the Sinana was increased by 2.3, 2.7 and 3.2°C in the near century (2030's), mid century (2050's) and end century (2080's) under RCP4.5, respectively (Table 2). Also, under RCP8.5, it increased by 2.4, 3.2 and 3.2°C in the near century (2030's), mid century (2050's) and end century (2080's), respectively (Table 2). For the Robe area, the mean maximum temperature was increased by 1.9, 2.3 and 2.7°C in the near century (2030's), mid century (2050's) and end century (2080's) under RCP4.5, respectively (Table 2). In addition, under RCP8.5, it was increase by 2.0, 2.7 and 3.9°C in the near century (2030's), mid century (2050's) and end century (2080's), respectively (Table 2).

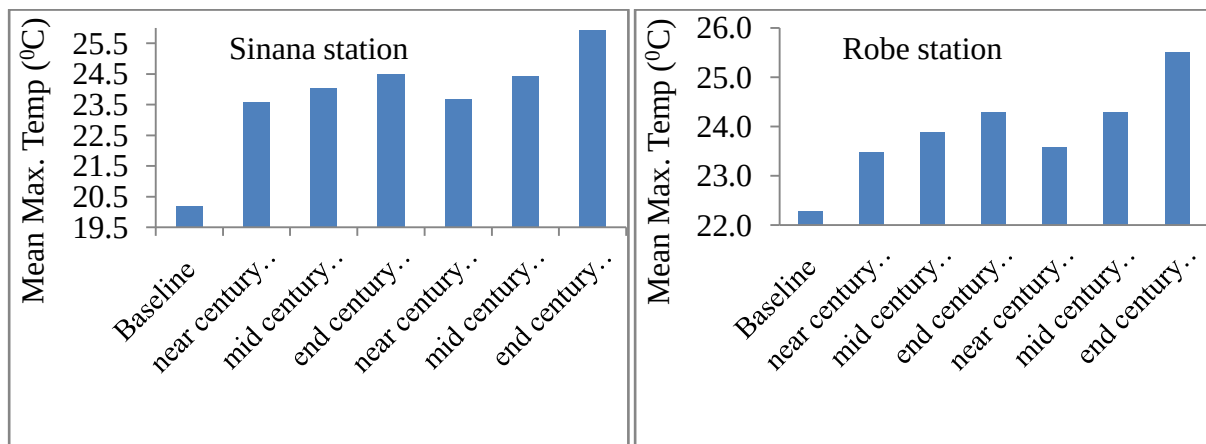
By comparing the increment of mean annual maximum temperature, end century (2080's) under RCP4.5 and mid century (2050's) and end century (2080's) under RCP8.5 were increased significantly at both locations (Figure 6). The study also showed that at the high emission scenario, the highest mean maximum temperature was expected for the study area.

Table 2: Change in annual rainfall (%) and temperature (difference in °C) by near century (2030's), mid century (2050's) and end century (2080's) under RCP4.5 and RCP8.5 from baseline period (1984-2016).

Sinana station					
	Rainfall (%)	Max.Temp. (°C)	Min. Temp. (°C)	Mean Temp. (°C)	CO2 concentration(ppm)
Baseline	905.13	21.28	9.59	15.44	369
RCP4.5-near century	+18.8	+2.30	+0.14	+1.22	423
RCP4.5-mid century	+15.2	+2.73	+0.62	+1.68	487
RCP4.5-end century	+20.3	+3.16	+1.12	+2.14	532
RCP8.5-near century	-56.95	+2.41	+0.31	+1.36	432
RCP8.5-mid century	+18.4	+3.15	+1.16	+2.15	571
RCP8.5-end century	+15.0	+3.15	+2.63	+2.89	950

Robe station					
Baseline	812.37	21.57	8.07	14.82	369
RCP4.5-near century	+33.06	+1.91	+1.61	+1.76	423
RCP4.5-mid century	+29.58	+2.33	+2.10	+2.21	487
RCP4.5-end century	+32.64	+2.74	+2.54	+2.66	532
RCP8.5-near century	+30.67	+2.00	+1.77	+1.89	432
RCP8.5-mid century	+34.56	+2.73	+2.63	+2.68	571
RCP8.5-end century	+31.15	+3.91	+4.07	+4.01	950

CO₂ concentration (Araya et al, 2015, Jones and Thornton, 2013).

**Figure 6:** Mean annual maximum temperature for baseline and all ensembles of GCM output under RCP4.5 and RCP8.5 scenarios.

Mean monthly maximum temperature

Projected mean monthly maximum temperature at Sinana and Robe areas in most months for all time slices (2030's, 2050's and 2080's) under both selected RCPs scenarios was significantly increased when compared with the baseline. The highest average maximum temperature increment was

expected by ensembles of all GCMs in the end century (2080's) under RCP4.5 and RCP8.5 scenarios at Sinana and Robe stations, respectively (Figure 7). The lowest average maximum temperature for upcoming century was expected by ensembles of all GCMs in the near century (2030's) under RCP4.5 scenario at both study areas. The results showed that the mean monthly maximum temperature was

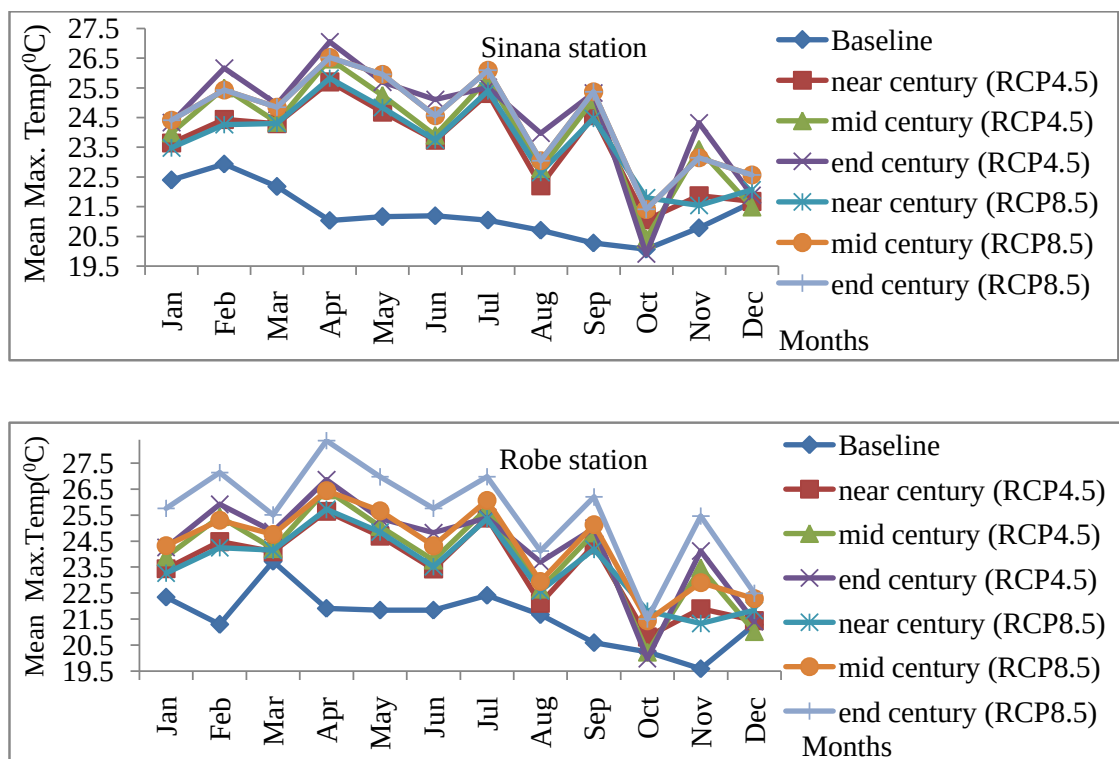


Figure 7: Mean monthly maximum temperature for baseline and all ensembles of GCM output under RCP4.5 and RCP8.5 scenarios.

increased at cropping time as compared with baseline at Sinana and Robe areas.

In the present study, future projected air temperature change was investigated and it was shown that the mean air temperature was increased by 1.22°C at Sinana and 1.76°C at Robe in the near century (2030's) under RCP4.5 scenario. Additionally, the mean air temperature was increased by 1.68 and 2.15°C at Sinana and 2.21 and 2.68°C at Robe in the mid century (2050's) under RCP4.5 and RCP8.5 scenarios, respectively. The present study also showed that the mean air temperature was significantly increased by 2.14 and 2.89°C at Sinana, while 2.66 and 4.01°C at Robe in the end century (2080's) under both scenarios. For the IPCC mid-range emission scenario, the mean annual temperature will increase in the range of 0.9 to 1.1°C by 2030's, 1.7 to 2.1°C by 2050's and 2.7 to 3.4°C by 2080's in Ethiopia as compared with the 1961-1990 normal, while a small increase in annual precipitation is expected over the country (Belay and Getaneh, 2016).

CONCLUSIONS

Climate change is believed to cause the most damaging

impacts on agricultural practices in developing countries such as Ethiopia. In Ethiopia, climate variability and change form a serious concern because the country's economy is almost totally dependent on rain fed agriculture which is the most vulnerable agricultural sector. In the present study, climate change and variability had impacts on agricultural activities in projected future climate scenarios. Models alone do not provide an answer for upcoming climate problems. Thus, there was a need for sustained integrated research to overcome the impacts of climate change and variability, especially at the district and farm levels. Researchers from natural and social sciences need to work together to come up with workable solution for adapting future climate variability and changes. Fully integrated environment- crop-climate modeling is currently in its infancy in Ethiopia, therefore the needs for further development and extension to include the environment conservation is a priority for research.

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APPENDICES

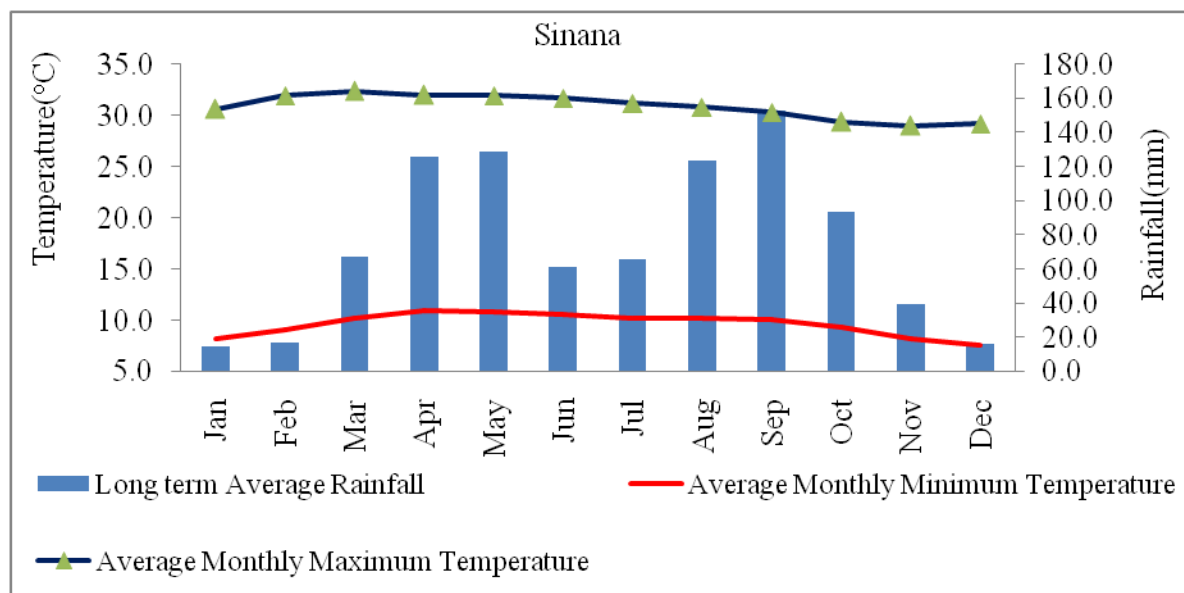


Figure 1: Long term average rainfall and temperature of Sinana Station (1984-2016).

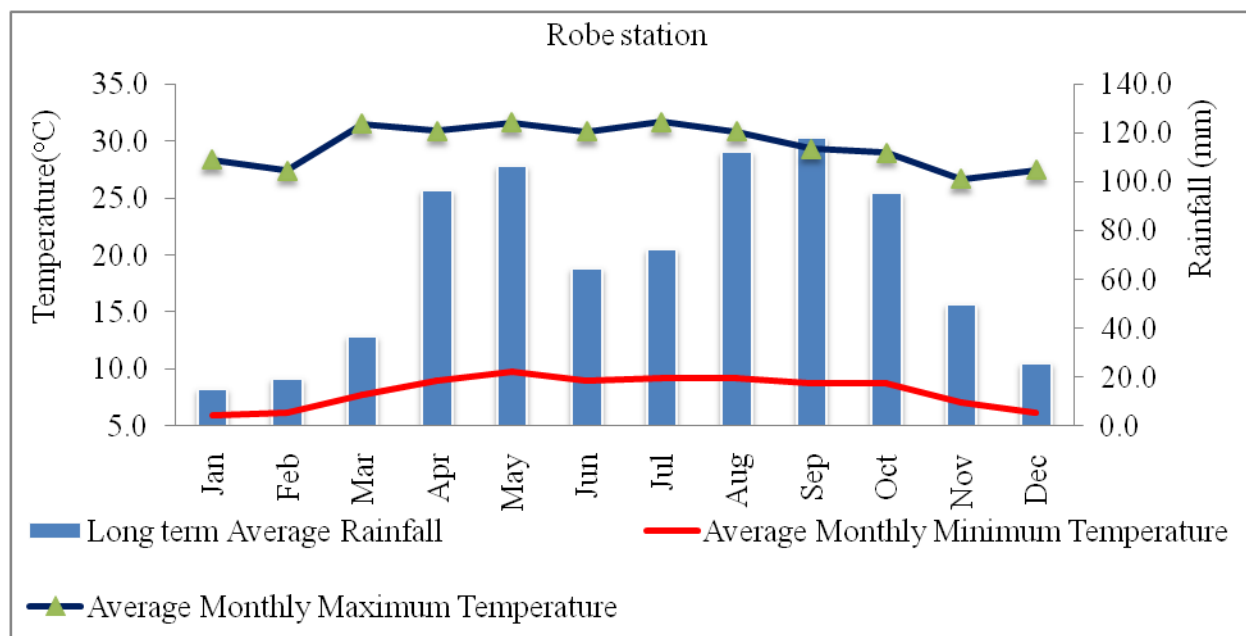


Figure 2: Long term average rainfall and temperature of Robe Station (1984-2016).