Assessing impacts of future climate on the crop water requirement and growth period. A case of Lake Hawassa watershed, Ethiopia

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Research Article

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Assessing impacts of future climate on the crop water requirement and growth period. A case of Lake Hawassa watershed, Ethiopia

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Abstract

Background: Assessing the influence of climate change on the crop growth period, water requirement, and drought conditions is important for the integrated planning of the production system. This study assessed the impact of climate models from the Coupled Model Inter-comparison Product (CMIP5) on Crop Water Requirement (CWR), Length of Growth Period (LGP), and drought conditions. This study applied two regional climate models that have shown better performance for the evaluation criteria during the historical period. Drought analysis was conducted for different classes of drought index using standardized anomalies of rainfall (S-index) from climate models.

Results: The future growing season of the area on average for all the years is between April 15 and May 1. The period between April 15 and May 1 marks the onset time and the end of September is the cessation time having LGP ranging from 150-160 days. Crop water requirement was projected to increase on average from the base period on both RCP 4.5 and RCP 8.5 scenarios. Analysis of drought prediction shows a few cases of extreme drought during the 2050s and 2080s under RCP 8.5. Furthermore, the 2050s has registered the lowest number of years with a positive S-index value indicating the projected scarcity of precipitation during these periods under RCP 8.5.

Conclusion: This study provides information on the impacts of climate change on crop growth periods, water requirements, and drought conditions. Therefore, understanding their future changes will enable the preparation of a better plan for the adaptation and mitigation of impacts.

Keywords: CMIP5; Drought; Growth period; Lake Hawassa Watershed; Water requirement.

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1 Background

Climate change is predicted to cause variability in future precipitation and temperature, which are important variables where crop production depends. Future climate variability is projected to affect water management at many locations (IPCC 2007). Possible declines in crop production, water availability, and drought due to climate change have been a concern of many recent studies (Burke et al. 2009; Thornton et al. 2010; Masia et al. 2021; Stringer et al. 2021). However, in this study region, the influence of climate variability and change is not well quantified and the response of Maize water requirement to climate change has not been well known. Climate change will alter different variables that are affecting crop production, soil moisture, drought, and evapotranspiration (Kay and Davies 2008; Secci et al. 2021; Gomez-Gomez et al. 2022). Studies have also shown the regional impact of climate change on water resources, by reducing future open water volume (Zeray et al. 2007; Tesfalem et al. 2018). The increasing drought amount and projected increment in potential evapotranspiration could directly affect the crop growing season and the related water requirements of the crop. Similar to many developing regions, crop production in the Lake Hawassa catchment is mainly dependent on rainfall. However, the distribution of rainfall over the region is highly variable and future alteration due to climate change is not well known.

The General Circulation Models (GCM) have been widely used in climate change studies. Dynamically downscaled GCM outputs are also currently considered to be suitable for impact prediction (Mengistu et al. 2021). Compared to GCMs RCMs provide better information and representation of different topographies at finer temporal and spatial scales (Giorgi et al. 2009). The Coordinated Regional Climate Downscaling Experiment in Africa (CORDEX) was produced under the coupled model inter-comparison project phase 5 (CMIP5) has produced many regional climate models and their scenarios in the Representative Concentration Pathways (RCP). The evaluation and application of CORDEX outputs were widely reported for the water resource impact assessment in Ethiopia (Ashaley et al. 2020; Tesfaye et al. 2020; Alehu et al. 2021; Asnake et al. 2021; Mengistu et al. 2021).

Regardless of other factors Crop Water Requirement (CWR) and Length of Growth Period (LGP), are influenced by potential evapotranspiration. The LGP is defined as the period between which an optimum soil moisture condition is met for the water demand of a certain crop (FAO 1978). Under normal conditions, crop productivity can be sustained with an adequate amount of soil moisture for evapotranspiration requirement by the crop. When this moisture drops the crop is under stress, which marks the cessation period. Different methods have been proposed to estimate the length of growth periods in Sub-Saharan Africa. Some of these methods are rainfall-dependent (Anyadike 1993; Matthew et al. 2017), while others depend on rainfall, temperature, and evapotranspiration (Omotosho 2002; Odekunle et al. 2005). The common method adopted from the FAO approach defines the LGP as the number of days in a year when rainfall exceeds half of potential evapotranspiration (FAO 1978). The FAO-Penman-Monteith method requires detailed information on data such as air temperature, humidity, radiation, and wind speed for the potential evapotranspiration estimation (Merugu and Mathyam 2015). The LGP can also be affected by other factors such as soil type, soil depth, water retention, release characteristics, air temperatures, and daylight hours (Merugu and Mathyam 2015). According to the FAO (1978) in any region the crop growing season can have three characteristics, the beginning period, humid periods, and end of the growing period. The beginning of the growing period occurs when the rainfall is equal to half of the potential evapotranspiration which is considered to be the normal rainy season. The Humid period is when the rainfall exceeds the potential evapotranspiration; and end of the growth period is when the rainfall falls below half of the potential evapotranspiration, which marks the dry period.

The crops water requirement is the amount of water required to meet the evapotranspiration demand. The crop water requirement is widely applied using the FAO Penman-Monteith (Allen et al., 1998) method of reference evapotranspiration (ET_o) estimation (Sawant et al. 2017). However, for future climates, the Hargreaves method can be applied (Hargreaves and Samni 1982). The crop coefficient (K_c) affects the amount of water required for a certain crop at different growth stages. Drought is another indicator of future climatic variability. Drought can affect future crop production and alter LGP and CWR. Studies have been conducted in Ethiopia to assess the impact of climate change on drought variability of future periods (Gidey et al. 2018). However, the common approach for assessing drought is through the standardized anomalies of rainfall (Agnew and Chappell 1999). Furthermore, the associated classification of drought indices such as extreme drought, severe drought, moderate drought, and no drought conditions would help in the decision-making of crop production.

This study analyzed the impact of climate change on Maize water requirement, growth period, and drought. This study applied two well-performing regional climate models from the RCM groups from the outputs of CORDEX Africa. The two regional models (CNRM5 and CSIRO MK3-6-0) sufficiently modeled the historical climate using the standard evaluation criteria. Furthermore, the impact was analyzed on the two Representative Concentration Pathways (RCP), that is the stabilization scenario (RCP4.5) and the worst-case scenario (RCP8.5). The length of the growth period was estimated using the standard approach of the FAO (FAO 1978). The influence of future climate on crop water requirements has also been analyzed to show its impact and implications for future food security in the region. In addition, the future drought expected in the region under different drought classes can be an input for regional scale decision making. Therefore, this study is particularly important for Maize production by being an input in the planning program and provides information in the preparation of a resilient production system.

2 Materials and Methods

2.1 Study area description

The study area is located within geographical coordinates of 6^{o} 45’ to 7^{o} 15’ N latitude and 38^{o} 15’ to 38^{o} 45’ E longitude. The total area of the watershed is approximately 1376 km^2 where the lake covers an area of 99 km^2 and the remaining 1276 km^2 of the watershed is occupied by land surface (Fig. 1). The area has a bimodal rainfall pattern and with average maximum and minimum temperature of 20 ^{o}C and 11 ^{o}C respectively. The analysis from four meteorological stations showed that the mean annual rainfall of the watershed was 1097.5 mm and June to September contributes 44% to the mean annual precipitation.

Rain-fed agriculture of annual crops is the major crop production scheme in the region in addition to a small area of mechanized farms. Agricultural land, at the household level, is mainly used for Maize, Sorghum, and root crop production. Seasonal and perennial agricultural land, wooded bush, and woodlands mainly represent land cover in the region (Halcrow 2008). Recently due to population increment, deforestation, and progressive replacement of other land use by agricultural land and built-up land have been shown (Gebreegziabher 2004; Gebeyehu Admasu 2015).

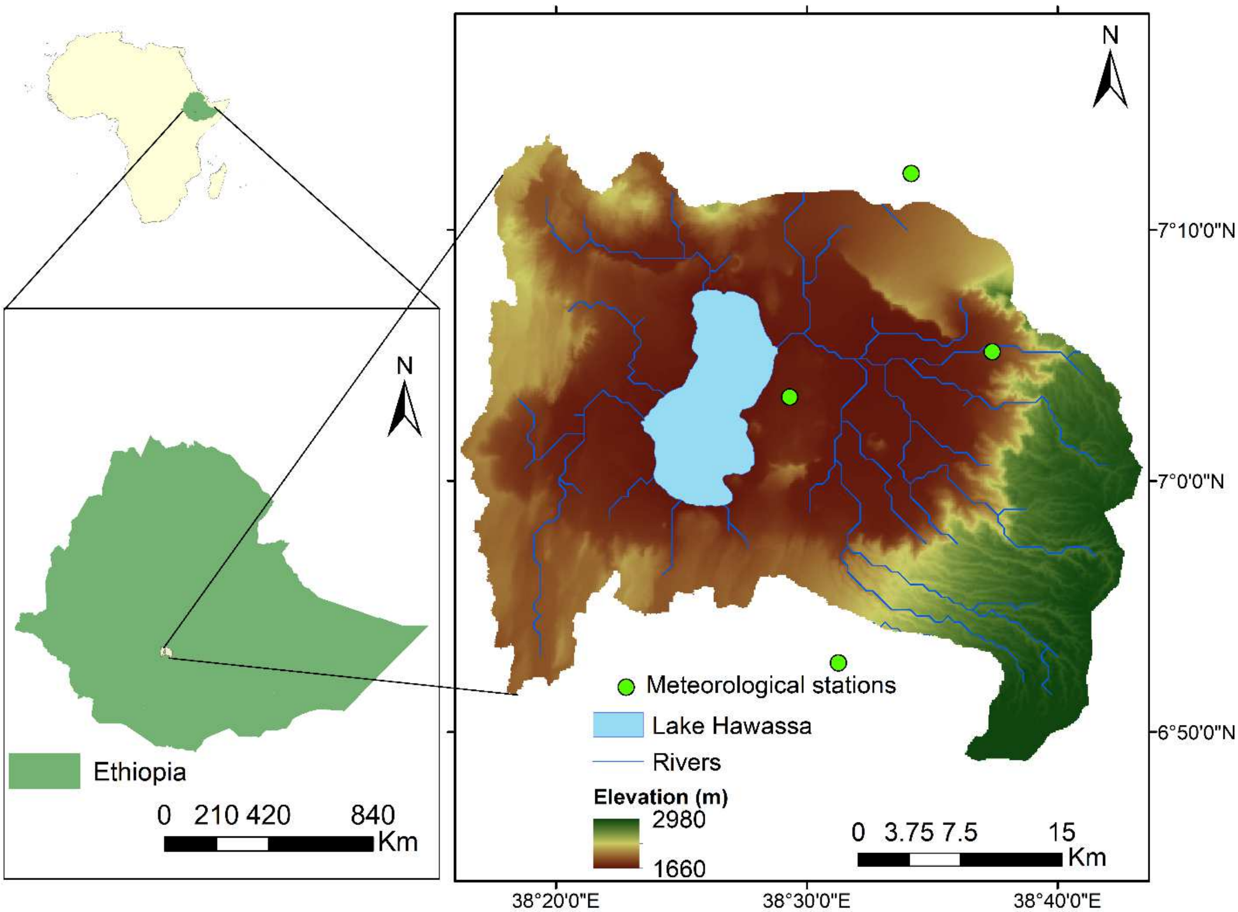


Fig. 1 The study area showing Lake Hawassa Watershed, Lake Hawassa, and rivers

2.2 Data sources and availability

The source of historical climatic data for the analysis was obtained from the National Meteorological Service Agency of Ethiopia (NMSA), shown in Table 1. The data include daily minimum and maximum temperatures, rainfall, solar radiation, relative humidity, and wind speed for climate characterization and computing reference evapotranspiration (ET_O). Future climate parameters (temperature, rainfall) were obtained from CORDEX Africa (Coordinated Regional Climate Downscaling Experiment in Africa) project for the two climate models (CSIRO-MK 3-6-0, and CNRM5). The model results are available for the RCP4.5 and RCP8.5 scenarios. These models are selected for the reason that regional models cover smaller areas so they can have a higher spatial resolution, for the same number of grid points as a global model.

Table 1 The historical and future climate data with their sources and temporal scale

Data type	Data description	Time period	Temporal Scale	Data source
Meteorology	Precipitation, temperature, relative humidity, solar radiation, and wind speed	1987-2017	Daily	NMSA
CNRM5	Precipitation, maximum and minimum temperature	1980-2005	Daily	https://esgf-node.llnl.gov/search/esgf-llnl/
CSIRO-MK 3-6-0	Precipitation, maximum and minimum temperature	1980-2005	Daily	https://esgf-node.llnl.gov/search/esgf-llnl/

2.3 Climate model validation and bias correction

The climate change models applied for this study were derived from the Regional Climate Models (RCM) from the project of CORDEX Africa. The regional climate model has a resolution of 0.48° and it is widely used in most African countries (Ashaley et al. 2020; Mengistu et al. 2021). This study compared several climate models with a reasonable spatial resolution to retrieve data for two climate variables (rainfall and temperature) at a monthly time scale. Before using climate models to simulate future climate fluctuations, it is necessary to evaluate how well models represent the historical and present climate. Among the several options used to validate the climate models, this study used both coefficients of determination (R^2) and daily variance of the observed and regional model data to select the most appropriate model to predict the future climatic condition of the area.

Climate models usually provide bias in representing the local scale climate variables. This study has applied a CMhyd tool (Rathjens et al. 2016) to adjust the bias in the downscaled temperature and precipitation product. For temperature, we used a linear scaling approach, which corrects the monthly mean. Bias in precipitation from the regional model were adjusted using the local intensity scaling approach.

2.4 Historical and future crop evapotranspiration (ET_C)

This study applied the Penman-Monteith method (Eqn 1) to calculate the daily potential evapotranspiration using all climatological variables such as rainfall, maximum and minimum temperature, relative humidity, sunshine hours, and wind speed (Allen et al. 1998). The future potential evapotranspiration was estimated by the Hargreaves method (Eqn 2) due to the availability of only minimum and maximum temperatures for the future period.

$$ET_o = \frac{0.408\Delta(Rn-G\ )+\gamma\frac{900}{T+273}U^2(es-ea)}{\Delta+\gamma(1+0.34U^2)} \tag{1}$$

Where:

ET_o	Reference potential evapotranspiration [mm day^{-1}]
Rn	Net radiation at the crop surface [MJ m^{-2} day^{-1}]
G	Soil heat flux density [MJ m^{-2} day^{-1}]
T	Mean daily air temperature at 2 m height [°C]
U2	Wind speed at 2 m height [m s^{-1}]
e_s	Saturation vapour pressure [kPa]
e_a	Actual vapour pressure [kPa]
e_s-e_a	Saturation vapour pressure deficit [kPa]
Δ	Slope vapour pressure curve [kPa °C^{-1}]
γ	Psychrometric constant [kPa °C^{-1}]

$$PET = 0.0023 * Ra * (T_{max} - T_{min})^{0.5} * (T_{mean} + 17.8) \tag{2}$$

Where PET is the potential evapotranspiration rate (mm/day), T_{min} and T_{max} represent the minimum and maximum temperature, and T_{mean} is the daily mean temperature. Table 2 shows the reference potential evapotranspiration (ET_o) for the historical period.

Table 2 Long-term average daily and monthly potential evapotranspiration from Hawassa stations (1980-2010).

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ET_o (mm/month)	122.6	123.6	145.1	134.2	134.1	128.2	113.3	115.5	111.6	132.2	120.2	121.7

Crop water requirement for Maize grown in the study area was estimated from historical records (1980-2010) and the future model outputs. For this study, the water requirement of Maize was derived through a crop coefficient that integrated the combined effects of crop transpiration and soil evaporation into a single crop coefficient (K_c), as shown in Eqn (3) (Allen et al. 1998).

$$ET_c = K_c * ET_o \tag{3}$$

where; ET_o is reference evapotranspiration rate, K_c is crop coefficient, ET_c is crop evapotranspiration defined as the evapotranspiration from a disease-free, well-fertilized crop, grown in large fields, under optimum soil water conditions, and achieving full production.

2.5 Determination of Crop Coefficient (K_C)

For this study, the crop coefficient was determined using the FAO-56 method (Allen et al. 1998). The daily K_C values can be determined by assuming K_C constant during the initial and mid-season stages and assuming a linear relationship between K_C values at the previous stage and at the beginning of the next stages in the crop development and late-season stages. The daily K_C values during the crop development and late-season stages are calculated using Eqn (4). (Allen et al. 1998).

$$Kc,\mathrm{i} = Kc(prev) + [\frac{\mathrm{i}-\sum Lprev}{\mathrm{Lstage}}](Kc(next) - Kc(prev)) \tag{4}$$

Where, K_{Ci} = daily K_C value; K_C (prev) = K_C values at the previous stage; K_C *(next)* K_C values at the next stage; L_{prev} = length of previous stages; L_{stages} = length of the estimated growing stage.

Table 3 shows the K_C values for Maize in different growth stages that are grown in a tropical region having an average rooting depth of 60 cm. However, this study considered only the first three growth stages (the Initial, Development, and Late-Season) due to the sensitivity of these growth stages to water demand. In addition, the average annual water requirement for the future periods of 30 years (2020, 2050, and 2080) was analyzed to depict the change in the future.

Table 3 *Kc* values taken from FAO (Allen et al. 1998)

Stages	Initial	Development	Mid-Season	Late-Season	Total
Kc	0.3	1.2	1.2	0.35	
(Days)	20	35	40	30	125 days

2.6 Onset Date, Cessation Date, and Length of Growing Period (LGP)

In this study, the onset, cessation date, and LGP of a growing season in the study area were determined from the relationship between rainfall and potential evapotranspiration (PET). However, the LGP is not only dependent on the rainfall amount, rather it can be influenced by the type of soil, water retention, air temperatures, and daylight hours (Merugu and Mathyam 2015). Among the several methods developed to determine the LGP (Ashok 1979; Sivakumar and, Maidoukia 1993), this approach uses the methods developed and dependent on rainfall and PET (FAO, 1978; Merugu et al. 1999). This approach was selected due to the limited availability of other factors (soil, water retention, air temperatures, and daylight hours) in the required scale for the study region. In this regard, the onset date is when rainfall ≥ 0.5*PET, and the offset date is when rainfall ≤ 0.5*PET and the LGP is the difference between the offset date and the onset date. The length of the growing period as defined by FAO (1978) is the period during a year when rainfall exceeds half the potential evapotranspiration (Fig. S1 of the Supplementary Material). Accordingly, the onset data is the beginning of cropping period where optimum soil moisture is available for crop production. On the other hand, the cessation data is when the crop is under stress to absorb water due to moisture deficit in the soil.

2.7 Estimation of drought index

This study has used the standardized anomalies of rainfall (S) to analyze the different drought classes. This study applied the standardized anomalies of rainfall (S) to calculate and assess the frequency and severity of droughts (Agnew and Chappell 1999) as shown in Eqn (5).

$$S = \frac{[P_t - P_m]}{\sigma} \quad (5)$$

Where S is the standardized rainfall anomaly, P_t is the annual rainfall in year t, P_m is the long-term mean annual rainfall over a given period of observation, and σ is the standard deviation of rainfall throughout the observation period. The drought severity classes are categorized in this study as extreme drought (S < -1.65), severe drought (-1.28 > S> -1.65), moderate drought (-0.84 > S > -1.28), and no drought (S > -0.84).

3 Results and discussions

3.1 Validation of climate models

The correlations of precipitation, minimum temperature, and maximum temperature with observations were done to select suitable models for the study region. The two climate models such as CNRM5 and CSIRO-MK 3-6-0 perform well on reproducing rainfall at a correlation coefficient (R^2) value of 0.74 and 0.71 respectively (Fig. 2b and c). Furthermore, the climate models have shown a reasonable capacity in simulating rainfall on a monthly basis (Fig. 2a).

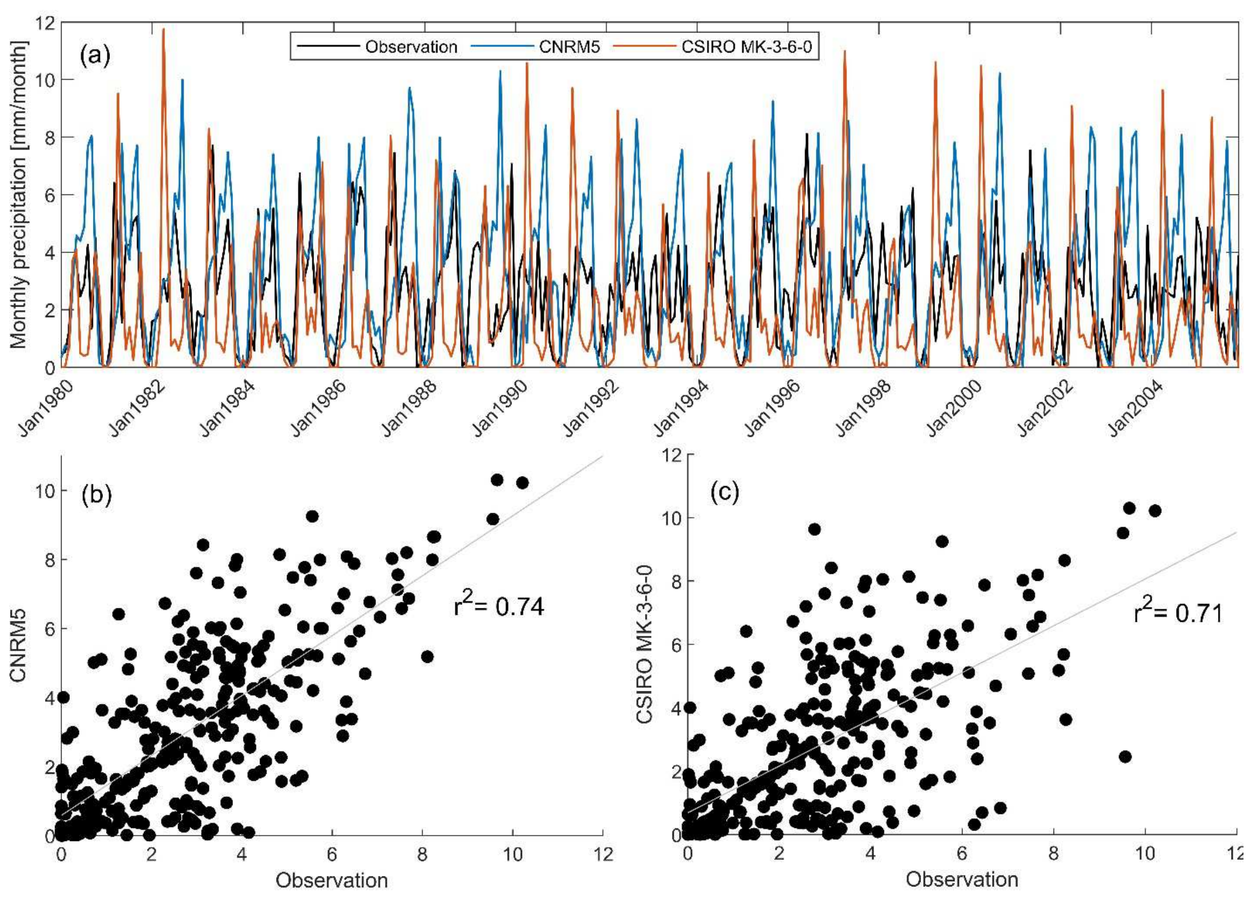
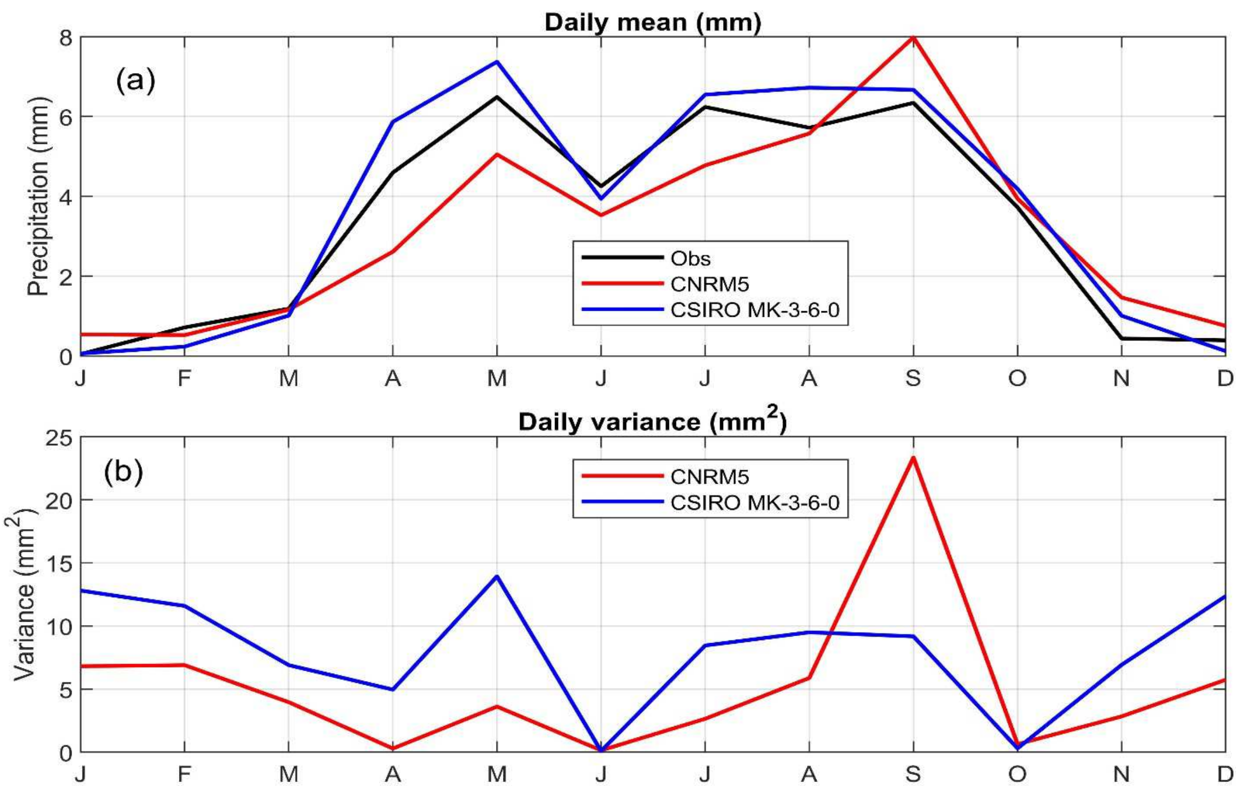


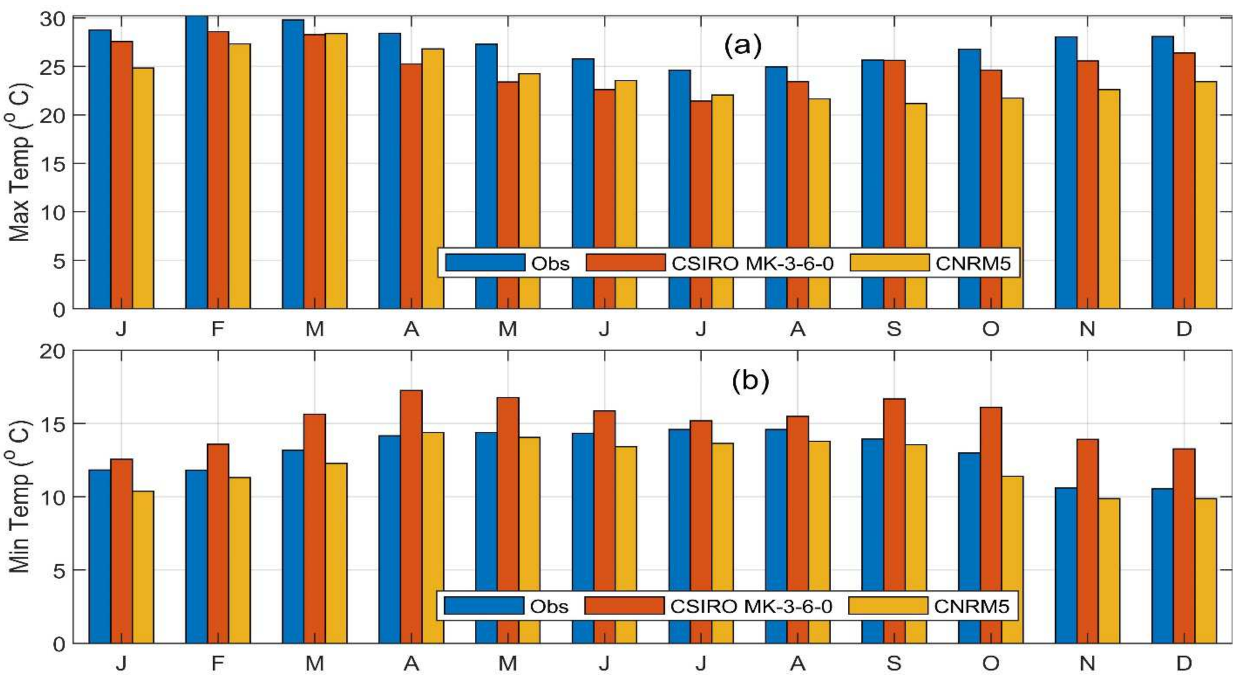
Fig. 2 (a) Comparison of the two climate models (CNRM5 and CSIRO MK-3-6-0) and observed rainfall on a monthly basis and the correlation coefficient between (b) CNRM5 and (c) CSIRO MK-3-6-0 with the observation for the baseline period (1980-2005)

The two complementing models were also tested for their performance in simulating the daily rainfall on regional scales. The calculated daily means (Fig. 3a) and variances (Fig. 3b) show an acceptable simulation of the historical period. For the CNRM5 and CSIRO MK-3-6-0 models, the annual variability of the monthly mean rainfall data is acceptable for the monthly simulation. For the CSIRO MK-3-6-0 models, most months were better represented captures by the observations, while other months (April, May, and Aug) showed a slight difference. Furthermore, the CNRM5 model has a general tendency to underestimate the monthly variance in most months of the year, while other months have overestimation in some months (e.g Aug to Dec). For the daily variance, the CNRM5 models have the highest variability while the CSIRO-MK-3-6-0 presented a slight variance (Fig. 3b).



3.2 Maximum and minimum temperature

It is seen from Fig. 4 that, both models underestimated the maximum temperature while for minimum temperature, the CSIRO MK-3-6-0 model has overestimated in all months and CNRM5 is underestimated except in April. The analysis shows maximum temperature was well captured by CSIRO MK-3-6-0 and the minimum temperature is better captured by CNRM5. Furthermore, the models can more accurately reproduce monthly and seasonal maximum and minimum temperature values since their monthly and seasonal variations are less than the projected monthly maximum and minimum temperature for a future period (Fig. 4). With this regard, the CNRM5 model groups have more likely reproduced the minimum temperature than the CSIRO MK-3-6-0 model. In addition, the CSIRO MK-3-6-0 model is better at tracking the mean maximum temperature than the CNRM5 model. Therefore, for further potential evapotranspiration estimation, both models were used by considering their average values.



3.3 Projected rainfall under the CNRM5 model

The projected rainfall in the study regions was analyzed for the three-time periods of the 21st century (2020, 2050, and 2080s). The rainy season (Jun, July, and August) for the future periods shows a reduction under the RCP 4.5 scenario for the periods of 2020, the 2050s, and 2080s. However, the future rainfall shows increment for the dry seasons (Oct-Dec and Jan-Apr) for the same future periods. For the rainy season at the end of the 21st century, a maximum reduction was observed during June from 172.9 mm/month to 155.7 mm/month under the RCP 4.5 scenario (Fig. 5a). The projected rainfall under the RCP 8.5 scenario reveals a change in the rainy season shown in Fig. 5b from the baseline period. Reduction of rainfall in the rainy season was shown under the RCP 8.5 scenario for the periods of 2020, the 2050s, and 2080s, but the future rainfall shows an increment for the dry seasons. The reduction of the future rainfall in the rainy season will have a warning for the region where rain-fed Maize production depends on this season.

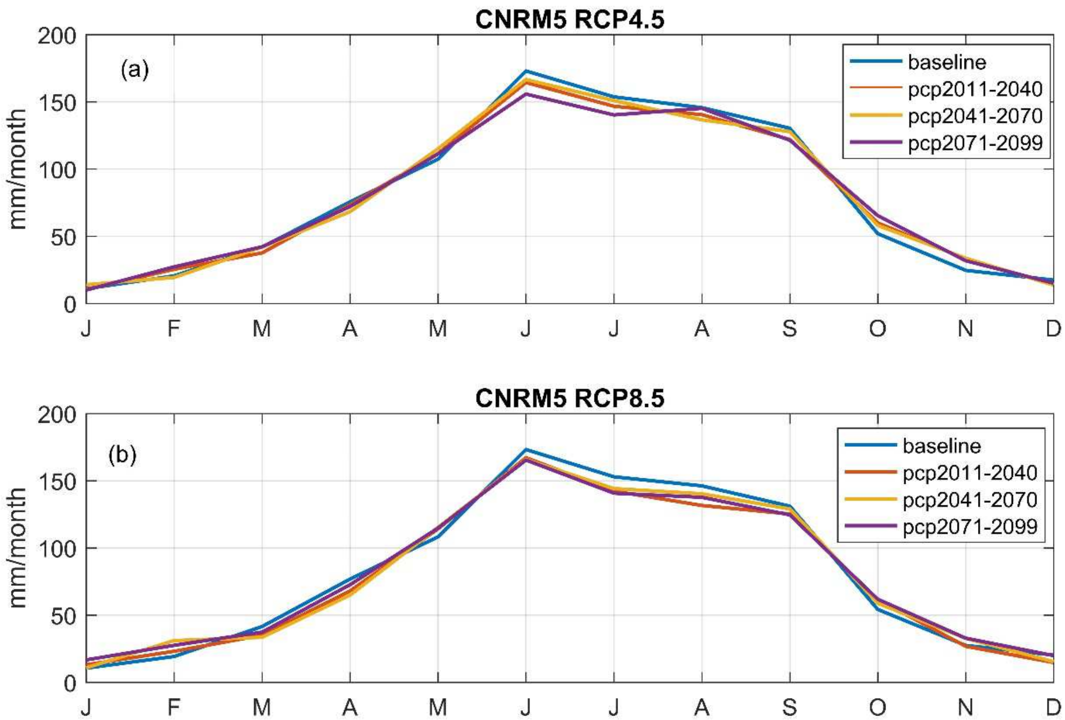


Fig. 5 Projected monthly rainfall under the CNRM5 model for RCP 4.5 (a) and RCP 8.5 (b) scenario for future periods

3.4 Projected potential evapotranspiration for future water requirement

Future PET has shown reductions mainly in the wet seasons of June, July, August, and September. However, a relative increase is projected for the regional dry months such as January, February, March, April, and through October, November, and December during the 2028s on RCP 8.5 (Fig. 6a). Similarly, during the wet seasons (June, July, August, and September) PET was reduced for most future periods. In addition, the same increase in PET is projected for mostly dry months (January, February, March, April, and through October, November, and December) on RCP 4.5 (Fig. 6b).

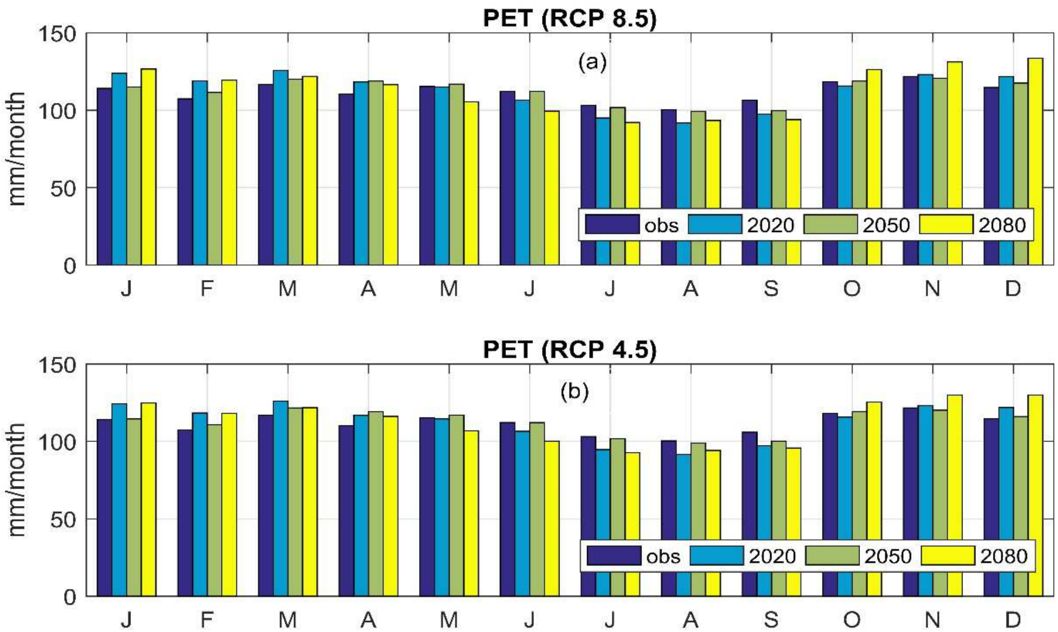


Fig. 6 Projected PET at different time horizons for (a) RCP 8.5 and (b) RCP 4.5

3.5 The historical and future growth periods under the CNRM5 model

From the estimated PET using the Penman-Monteith method, the overlap between half of PET and monthly historical precipitation (PCP) was used to determine the regional LGP. The result shows on average the end of March was the onset month and October was the cessation month of the area with a maximum LGP of 190 days for the period of 1980-2010 (Fig. 7).

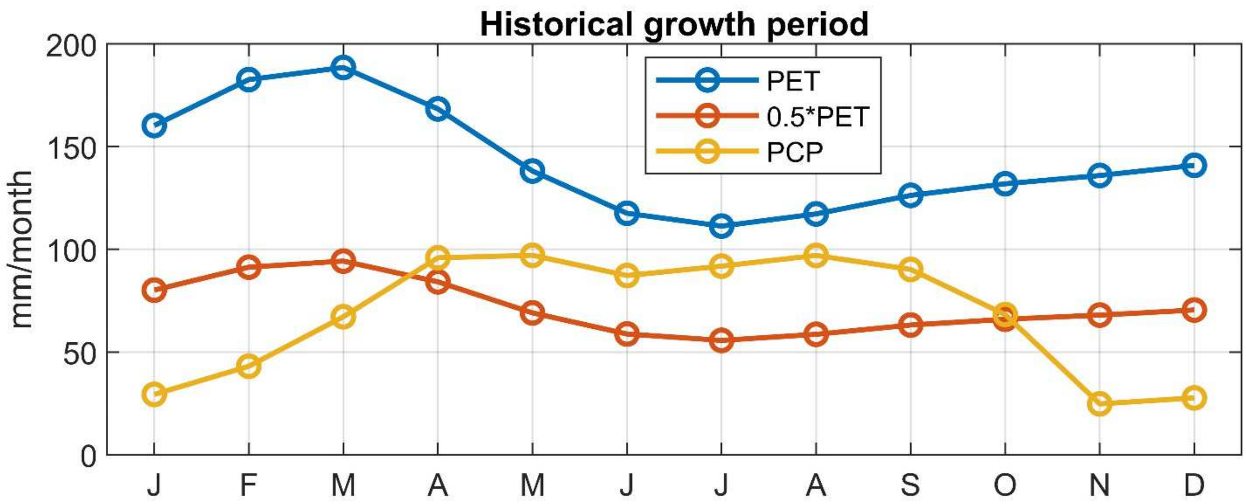


Fig. 7 The historical (1980-2010) length of growth period LGP of Maize over Lake Hawassa watershed.

Using the same procedure, outputs of CNRM5 model were applied for precipitation and the average temperature from the two model groups and the Hargreaves method to project the onset, offset, and LGP of the area for the future time horizons. Fig. 8a and b show the length of growth periods for the 21st century under RCP 4.5 and RCP 8.5 scenarios respectively. The result reveals for the period of the 2020s on average April 1-15 is likely to be the onset time and the beginning of October is the cessation time of the area. Hence, the area will have a maximum LGP of 180 days with humid periods of nearly 3-months (Fig. 8a). During the 2050s the LGP has remained nearly the same as in 2020 where the onset time is April 1-15 and the cessation time of the area is the end of September. In this period, the maximum LGP is reduced to 150 days. Whereas the end of the 21st century (2080s) has resulted in the minimum LGP on the area with an average LGP of 140 days under the RCP 4.5 scenario.

The future shift in the LGP of Maize under the RCP 8.5 scenario is shown in Fig. 8b. Based on this assessment the period of the 2020s on average April 1-15 is likely to be the onset time and the end of September is the cessation time of the area. Hence, the area will have a maximum LGP of 165 days with humid periods of nearly 3-months in June, July, and August (Fig. 8b top panel). The period 2050s, remained nearly the same as in 2020 where the onset time is April 1-15 and the cessation time of the area is the end of September. In this period, the maximum LGP is reduced to 150 days. Whereas the end of the 21st century (2080s) has resulted in the minimum LGP on the area with an average LGP of 138 days under the RCP 8.5 scenario (Fig. 8b bottom panel).

The future growing season of the area on average for all the years is between April 15 to May 1 onset time and the end of September is the cessation time with LGP ranging between 150-160 days. Even though the future is estimated to be suitable for rain-fed agriculture the short humid period is an indicator of the incidence of water stress in the future time horizons. In general, comparing the historical and the future growing season of the area, there is a time when both local seasons '*Bega'* (between October and February) and '*Belg'* (stays from March to May) remain mostly not operational for the rain-fed agriculture. However, the future is anticipated to be suitable for rain-fed agriculture during the local rainy season called '*Kiremt'* (stays from June to September). There is also a considerable change in the onset time from April to May and offset time from September to October and a decrease in the length of the growing season is an early warning that requires redesigning the traditional agricultural practice and utilizing optimally the anticipated rainfall for the future periods.

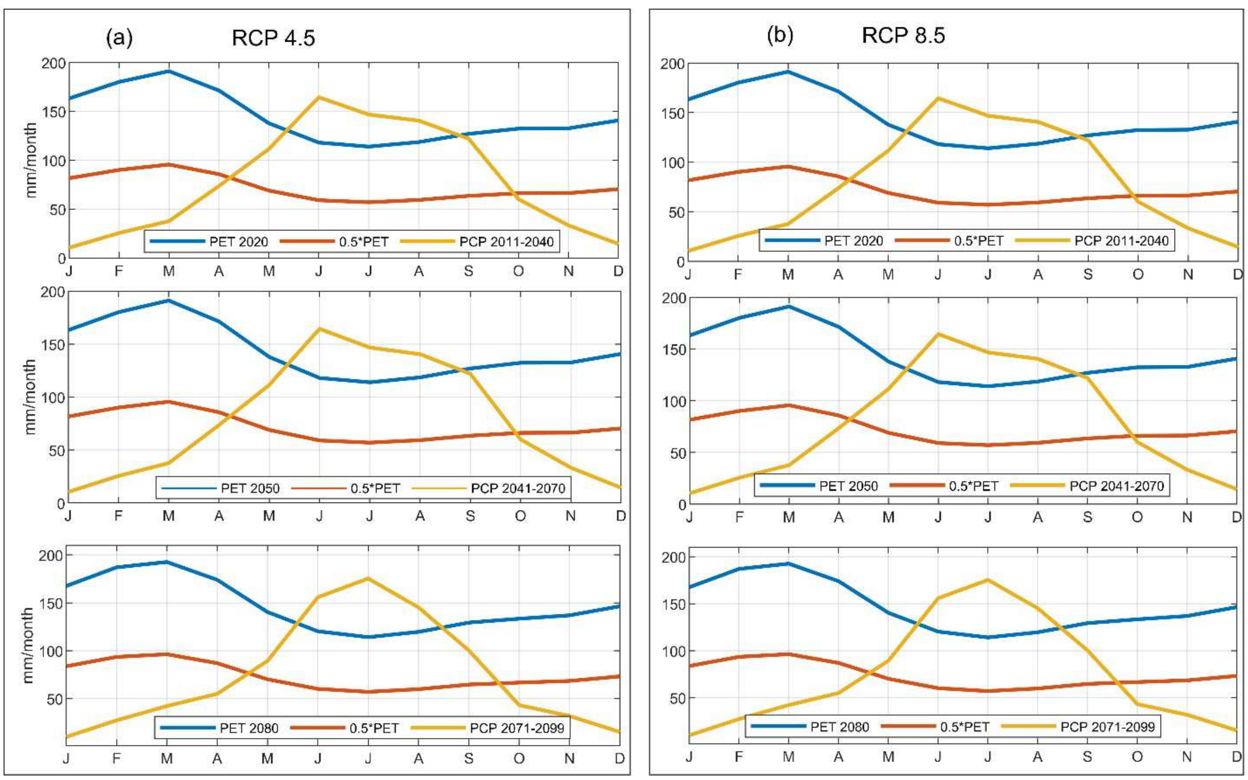


Fig. 8 Future growing season of Lake Hawassa watershed for the years 2020, 2050, and 2080 under CNRM5 RCP 4.5 and scenario

3.6 Maize water requirement under climate change

Maize water requirement in each growing stage by scenarios is presented in Fig. 9. Accordingly, under RCP4.5 scenarios, Maize would require 518.1mm by 2020s, and 528.4 mm by 2080s respectively for the initial growth period. For the same scenario (RCP4.5), the Maize shows an increment in the CWR from 2072.4 mm to 2213.25 mm from the 2020s to the 2080s respectively. During the late season, there was also a remarkable increment in the CWR of Maize up to the end of the 21st century. Therefore, the crop water demand was projected to increase on average from the base period for RCP 4.5 emission scenarios. Here the increment of CWR is attributed mainly to the increase in the projected evapotranspiration of the two climate models (CNRM5 and CSIRO MK-3-6-0) employed in this study. Similarly, under the RCP 8.5 scenario, the development stage has shown an increment from 2083mm to 2155mm from 2020 to 2080. This projection for the study region suggests additional demand for water to supplement the rain-fed farming system.

As it is already discussed in the projected PET (*Section 3.4*), the highest and lowest PET was in March and December respectively. This result is almost consistent with the Maize water requirement for the same period. During the base period, the total water requirement for the production of Maize was about 3180.4mm and increased to 3258.7mm at the end of the 2080s for all stages. This difference in the water demand of Maize is possibly due to the distinction in the length of the growing period at the periods. It has been discussed that under RCP4.5 scenarios the future LGP shows a reduction mainly due to an increment in the PET.

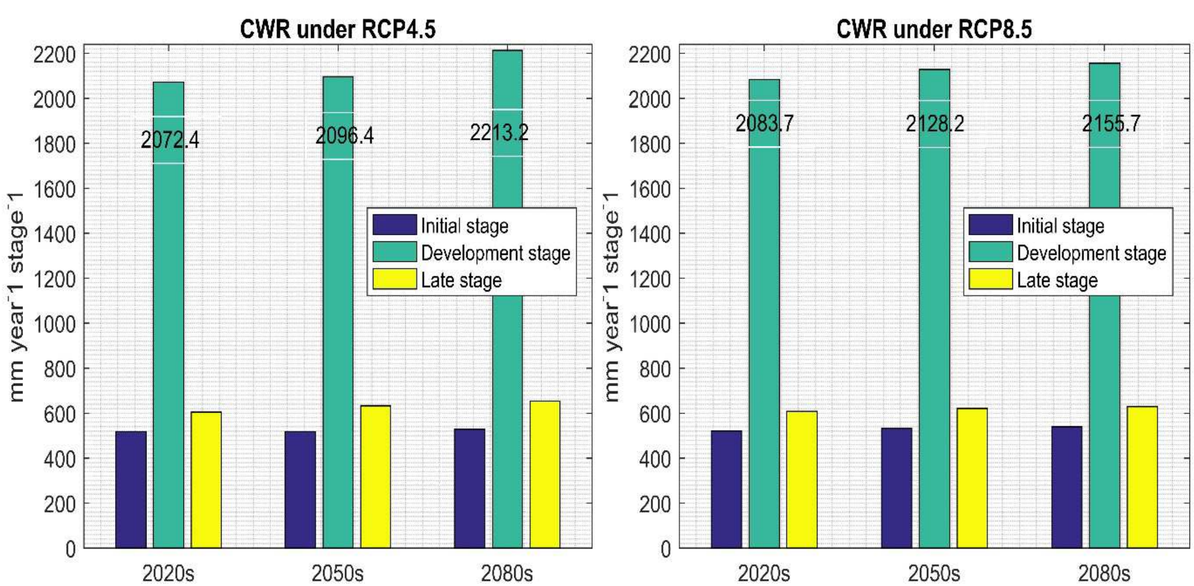


Fig. 9 Annual future CWR (mm/growing stages) of Maize under different development stages for RCP 4.5 and RCP 8.5 scenarios

3.7 Analysis of drought severity classes

The standardized anomalies of rainfall (S) are presented here to describe the different classes of drought index for the region using the CNRM5 model under both scenarios (RCP 4.5 and RCP 8.5). Under the RCP 4.5 scenario, most of the standardized anomalies of rainfall (S) are negative indicating a water deficit during the 2020s (Fig. 10a). At the same time (2011-2040), the result reveals 2015 and 2027 were extreme drought years, and 2031 and 2038 are severe drought years. However, the other 26 years with (S > -0.84) has shown no drought years. The result also indicates 15 cases out of 30 years with positive departure with a maximum in 2026(+2.8) which shows the area has received good rainfall during these years and 15 years with negative anomalies shows a deficit of rainfall in the area for the period of 2011-2040. During the year the 2050s (2041-2070) there is no case which is resulted in extreme drought (Fig. 10b). However, three years showed a severe drought class in the years 2041, 2061, and 2069. The same analysis was also projected during the 2080s where there is only one case of severe drought in 2074. However, out of 30 years, 15 years have resulted in a positive S-index indicating good rainfall coverage across the years (Fig. 10c).

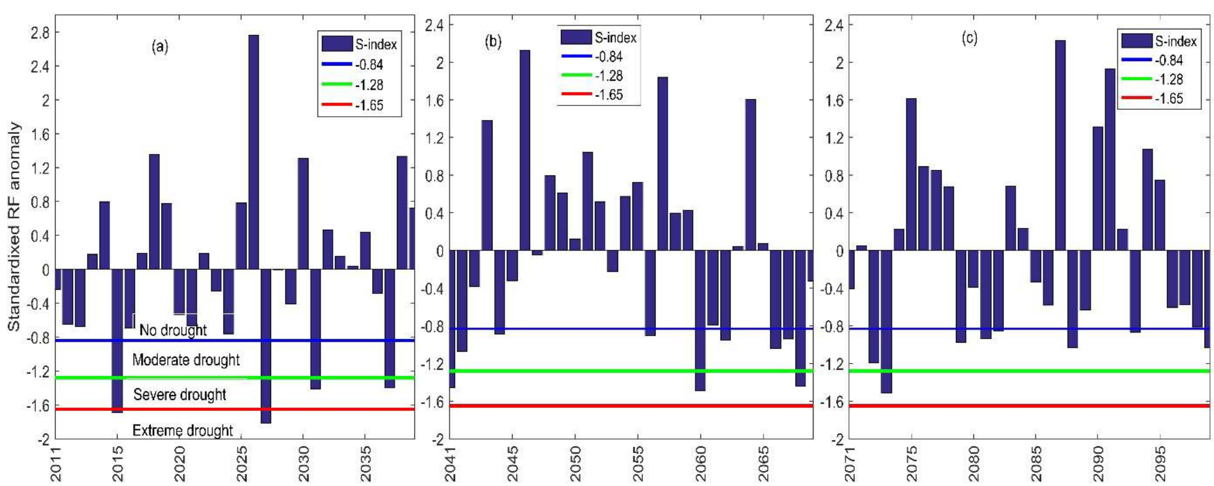


Fig. 10 Standardized rainfall anomalies of future precipitation of the future periods (a) 2020s, (b) 2050s, and (c) 2080s for the CNRM5 model under RCP 4.5 scenario

Fig. 11 also shows the standardized rainfall anomalies under the RCP 8.5 scenario for the three periods of 2020, 2050, and 2080s. Under this scenario, only a few cases of extreme drought were exhibited during the 2050s and 2080s.

Furthermore, relatively the year the 2050s has registered the lowest number of years (only 10 years) with a positive S-index value indicating the projected scarcity of rainfall during these periods (Fig. 11b). Comparatively the years the 2080s have more positive S-index than other periods, positive anomalies indicate the likely occurrence of good annual rainfall in the Lake Hawassa watershed (Fig. 11c).

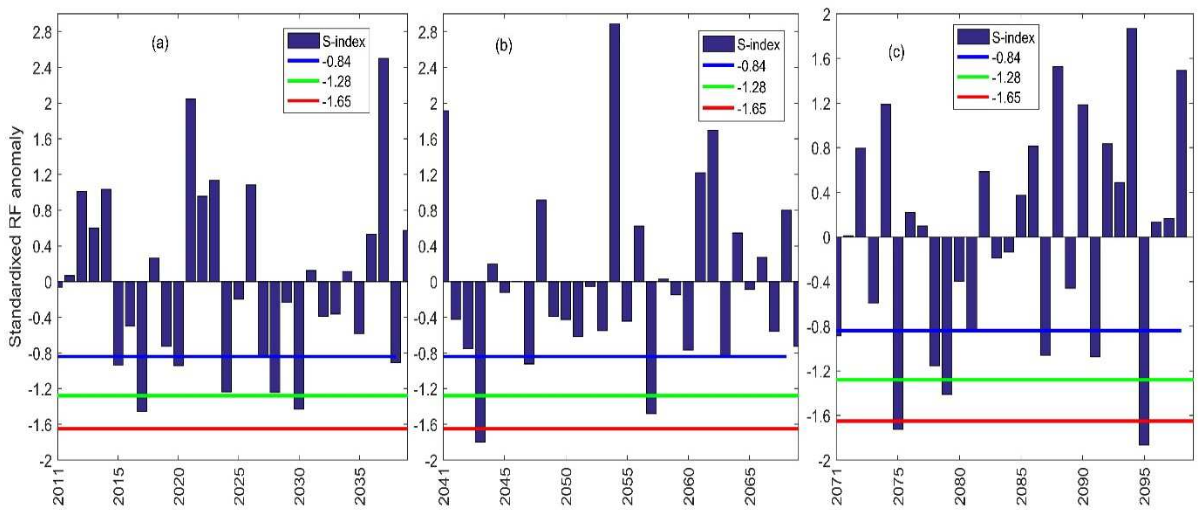


Fig. 11 Standardized rainfall anomalies of future rainfall of the future periods (a) 2020s, (b) 2050s, and (c) 2080s for the CNRM5 model under RCP 8.5 scenario

3.8 The implication of future LGP and CWR for the regions

The study analyzed the historical growth period of the Lake Hawassa watershed which is under the progressing anthropogenic influences similar to other places in Ethiopia (Gebeyehu Admasu 2015; Abraham and Nadew 2018). The analysis of LGP from the best fitting climate model (CNRM5) for the region was overlapped to show a possible shift in the LGP. Here the CNRM5 model for precipitation best describes the fit, whereas temperature estimation for both models (CNRM5 and CSIRO MK-3-6-0) show a regionally acceptable result. The analysis showed for Lake Hawassa watershed, the LGP has shown a reduction for the future period from the base periods (4-5 months) values. With an existing low economic and agricultural development in the regions, the result suggests an early warning to develop a coping and mitigation option to develop adaptive farming systems. In addition, the reduction in the LGP will also affect the farming practice for Maize production and further could cause a change in the suitable crop type for the region. The study by Thornton et al. 2010 showed moderate yield losses to be expected to be offset by crop breeding and agronomic approaches in the near future periods, while more severe yield losses may necessitate changes in crop types, even a shift to livestock-orientated production or abandonment of cropping altogether.

Another point worthy of consideration is that Maize production by rain-fed will be more problematic and the lower LGP will most likely rely on crops that are having shorter LGP in these regions. Furthermore, the increment of CWR could make Maize production more problematic. The previous section (*Section 3.6*) analysis has shown a projected increment of CWR from the base period's values under both scenarios. These increments are driven by an increase in the future temperature of the area, which would serve as a proxy for the estimation of evapotranspiration. Particularly, in these regions, crop production is dependent on a rain-fed system, which is erratic, by itself in nature, and this will lead to an increase in uncertain production of the crop in the future. To cope with these scenarios conservation of water in the field is required at a household scale and requires enhanced efficiency of irrigation systems. Furthermore, the shift in the crop types (Burke et al. 2009), which are demanding less water in the future or resistant to water stress, should be considered. Consequently, the development of improved germplasm and farmers' access to the improved seeds should be planned to strengthen breeding strategies to offset predicted yield declines (Burke et al. 2009; Thornton et al. 2010).

4 Conclusions

The impact of climate change is becoming a trait in many sectors. Quantifying its effect on the crop production factors such as length of growth periods (LGP) and crop water requirement (CWR) will enable better preparedness. This study has assessed the impact of climate change and its implication for the length of growth periods and water requirement of Maize. The study used two regionally downscaled climate models (CNRM5 and CSIRO-MK 3-6-0), which were well reproduced in the precipitation and temperature data over the historical period. The onset time for the average of all future periods is between April 15 to May 1 and the end of September is the cessation time with LGP ranging between 150-160 days. Predictions for the future growing season of the area show, two local seasons such as '*Bega'* (October to February) and '*Belg'* (March to May) could remain mostly not operational for the rain-fed agriculture. However, the local rainy season '*Kiremt'* (June to September) is anticipated to remain suitable for rain-fed agriculture under both RCP 4.5 and RCP 8.5 scenarios.

The crop water requirement of Maize during the late season has shown a remarkable increment in the CWR of Maize up to the end of the 21st century. Thus, the water requirement for Maize was projected to increase on average from the base period under RCP 4.5 scenarios. Similarly, under the RCP 8.5 scenario, the development stage of Maize has shown the largest increment of water requirement for the period of 2020 to 2080. Most of the standardized anomalies of rainfall (S) are negative under the RCP 4.5 scenario indicating a water deficit during the 2020s. Furthermore, in the year 2050s no case resulted in extreme drought, however, a severe drought class was shown in the years 2041, 2061, and 2069 under the RCP 4.5 scenario. On the other hand, during 2080s there was only one case of severe drought. The same analysis depict under RCP 8.5 scenario, only a few cases of extreme drought were exhibited during the 2050s and 2080s however, the year 2050s has registered a projected scarcity of precipitation during this period.

Overall this study showed the influence being resulting from two climate models on Maize production. Therefore, for the expected uncertainties of the climate models, it is recommended to include multi-model climate data analysis in the future. In addition, due to the limited availability of other data on large scale, the estimation of LGP should be interpreted carefully, and future studies should include finer spatial scale quantification of LGP by including measurements data such as soil moisture, water retention, air temperatures and daylight hours.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions

TA conceptualized the method, analysis, interpretation of the result, and write-up of the paper. AM, provided support in developing the manuscript and commented on previous versions of the manuscript.

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Abbreviations

GCM: General Circulation; RCM: Regional Climate Model; CORDEX: Coordinated Regional Climate Downscaling Experiment in Africa; CMIP5: Coupled Model Inter-Comparison Project Phase 5; RCP: Representative Concentration Pathways; CWR: Crop Water Requirement; LGP: Length of Growth Period; PET: Potential evapotranspiration; K_C: crop coefficient; ETC: crop evapotranspiration.

Declarations

Ethics approval and consent to participate

There is no ethical conflict.

Consent for publication

All authors read the manuscript and agreed for publication.

Competing interests

The authors declare that they have no competing interest.

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References

Abraham, Nadew (2018) Impact of Land Use Land Cover Dynamics on Water Balance , Lake Ziway Watershed, Ethiopia. Hydrol Curr Res 9:309

Agnew C, Chappell A (1999) Drought in the Sahel. GeoJournal 48:. https://doi.org/10.2307/41147385

Alehu BA, Desta HB, Daba BI (2021) Assessment of climate change impact on hydro-climatic variables and its trends over Gidabo Watershed. Model Earth Syst Environ. https://doi.org/10.1007/s40808-021-01327-w

Allen, R. Pereira, L. Raes, D. Smith M (1998) Crop evapotranspiration —guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Food and Agriculture Organization, Rome..

Anyadike RNC (1993) Seasonal and Annual Rainfall Variations Over Nigeria. Journal, Int Climatol 13:567–580

Ashaley J, Anornu GK, Awotwi A, et al (2020) Performance evaluation of Africa CORDEX regional climate models: case of Kpong irrigation scheme, Ghana. Spat Inf Res 28:735–753. https://doi.org/10.1007/s41324-020-00331-z

Ashok Raj PC (1979) Onset of effective monsoon and critical dry spells. IARI Research Bulletin No. 11. Water Technology Centre, IARI, New Delhi.

Asnake AB, Ayana MT, Awass AA, Goshime DW (2021) Transformation of climate and its sway on hydro-climatology using representative concentration pathways (RCP) in Geba catchment of Ethiopia. Model Earth Syst Environ 7:2439–2451. https://doi.org/10.1007/s40808-020-01029-9

Burke MB, Lobell DB, Guarino L (2009) Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. Glob Environ Chang 19:317–325. https://doi.org/10.1016/j.gloenvcha.2009.04.003

FAO (1978) Report on the agro-ecological zones project. V. 1: Methodology and results for Africa. Rome (Italy)

Gebeyehu Admasu T (2015) Urban land use dynamics, the nexus between land use pattern and its challenges: The case of Hawassa city, Southern Ethiopia. Land use policy 45:159–175. https://doi.org/https://doi.org/10.1016/j.landusepol.2015.01.022

Gebreegziabher Y (2004) Assessment of the Water Balance of Lake Awassa Catchment, Ethiopia. In: International Institute for Geo-Information and Earth Observation, Enschde, The Netherlands.

Gidey E, Dikinya O, Sebego R, et al (2018) Predictions of future meteorological drought hazard (~ 2070) under the representative concentration path (RCP) 4.5 climate change scenarios in Raya, Northern Ethiopia. Model Earth Syst Environ 4:475–488. https://doi.org/10.1007/s40808-018-0453-x

Giorgi; F, Jones; C, Asrar; GR (2009) Addressing Climate Information Needs at the Regional Level: the CORDEX Framework, 58th edn.

Gomez-Gomez J-D, Pulido-Velazquez D, Collados-Lara A-J, Fernandez-Chacon F (2022) The impact of climate change scenarios on droughts and their propagation in an arid Mediterranean basin. A useful approach for planning adaptation strategies. Sci Total Environ 820:153128. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.153128

Halcrow (2008) Rift Valley Lakes Integrated Natural Resources Development Master Plan Study project. Main report. Group Limited and Generation Integrated Rural Development GIRD consultants, Ministry of Water and Energy, Addis Ababa.

Hargreaves G, Samni Z (1982) Estimation of potential evapotranspiration. J Irrig Drain Div Proc Am Soc Civ Eng 108:

Kay AL, Davies HN (2008) Calculating potential evaporation from climate model data: A source of uncertainty for hydrological climate change impacts. J Hydrol 358:221–239. https://doi.org/https://doi.org/10.1016/j.jhydrol.2008.06.005

Masia S, Trabucco A, Spano D, et al (2021) A modelling platform for climate change impact on local and regional crop water requirements. Agric Water Manag 255:. https://doi.org/10.1016/j.agwat.2021.107005

Matthew O, Imasogie O, Ayoola M, et al (2017) Assessment of Prediction Schemes for Estimating Rainfall Onset over Different Climatic Zones in West Africa. J Geogr Environ Earth Sci Int 9:1–15. https://doi.org/10.9734/jgeesi/2017/31043

Mengistu AG, Woldesenbet TA, Dile YT (2021) Evaluation of the performance of bias-corrected CORDEX regional climate models in reproducing Baro–Akobo basin climate. Theor Appl Climatol 144:751–767. https://doi.org/10.1007/s00704-021-03552-w

Merugu T, Shashikala A MP (1999) Agro-Ecological sub regions of India for development and planning. NBSS Publ. 35. National Bureau of Soil Survey and Land Use Planning. Nagpur, India

Merugu T, Mathyam P (2015) Variability Study on the Length of Growing Period (Lgp) Using Ground and Space Based (Modis) Data for the. 452

Odekunle TO, Balogun EE, Ogunkoya OO (2005) On the prediction of rainfall onset and retreat dates in Nigeria. Theor Appl Climatol 81:101–112. https://doi.org/10.1007/s00704-004-0108-x

Omotosho J (2002) Synoptic Meteorology: Pathway to Seasonal Rainfall Prediction for Sustainable Agriculture and Effective Water Resources Management in West Africa but Nigeria in Particular. J Niger Meteorol Soc 3:

Rathjens H, Bieger K, Srinivasan R, et al (2016) Documentation for preparing simulated climate change data for hydrologic impact studies. URL: http://swat.tamu.edu/software/cmhyd/

Sawant S, Durbha SS, Jagarlapudi A (2017) Interoperable agro-meteorological observation and analysis platform for precision agriculture: A case study in citrus crop water requirement estimation. Comput Electron Agric 138:175–187. https://doi.org/10.1016/j.compag.2017.04.019

Secci D, Tanda MG, D’Oria M, et al (2021) Impacts of climate change on groundwater droughts by means of standardized indices and regional climate models. J Hydrol 603:127154. https://doi.org/https://doi.org/10.1016/j.jhydrol.2021.127154

Sivakumar MVK, Maidoukia A SR (1993) Agro climatology of West Africa: Niger. Information Bulletin No. 5.

Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 10 pp.

Stringer LC, Mirzabaev A, Benjaminsen TA, et al (2021) Climate change impacts on water security in global drylands. One Earth 4:851–864. https://doi.org/https://doi.org/10.1016/j.oneear.2021.05.010

Tesfalem A, Abraham W, Alemayehu M, Brook A (2018) Hydrological Responses of Climate Change on Lake Ziway Catchment, Central Rift Valley of Ethiopia. J Earth Sci Clim Change 09: https://doi.org/10.4172/2157-7617.1000474

Tesfaye TW, Dhanya CT, Gosain AK (2020) Modeling the impact of climate change on the environmental flow indicators over Omo-Gibe basin, Ethiopia. Model Earth Syst Environ 6:2063–2089. https://doi.org/10.1007/s40808-020-00813-x

Thornton PK, Jones PG, Alagarswamy G, et al (2010) Adapting to climate change: Agricultural system and household impacts in East Africa. Agric Syst 103:73–82. https://doi.org/10.1016/j.agsy.2009.09.003

Zeray L, Roehrig J, Chekol D (2007) Climate Change Impact on Lake Ziway Watershed Water Availability, Ethiopia. Proceedings of the International Joint Conference on Catchment and Lake Research.

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