IMPACT OF CLIMATE CHANGE ON IRRIGATION WATER REQUIREMENTS OF MAJOR CROPS AT GOBU SEYO DISTRICT, EAST WELLEGA ZONE, ETHIOPIA

***Habtamu Bedane[1], Teshome Seyoum[2]**

[1]Oromia Agricultural Research Institute, Bako Agricultural Engineering Research Center, Bako

[2]School of Water Resources and Environmental Engineering, Haramaya University, Ethiopia

*Corresponding Author e-mail: habtamubedane503@gmail.com

ABSTRACT

The study was carried out to investigate the likely impacts of climate change on irrigation water requirements of selected crops. CROPWAT 8.0 model was used to simulate the total crop water requirement as well as irrigation requirements for the present and the future decades. In addition to the base period (1990-2019), future scenarios (2023-2052) and (2053-2082) projections were made based on the output ensemble of 17 GCMs with aid of a MarkSim-GCM for two emission scenarios, the medium (RCP4.5) and the high (RCP8.5). The analysis demonstrates that the crop water needs of both crops changed from 4.55% to 7.89% under both scenarios (RCP8.5 and RCP4.5) and time horizons (2023-2052 and 2053-2082). The highest change of crop water requirements was recorded at high emission scenario (RCP8.5) and mid-term period and the lowest was detected at medium emission scenario (RCP4.5) with near-term period. The change in irrigation water requirements of the research area's selected crops ranged from -1% to 8.15%. The greatest increasing change was detected in the RCP8.5 with mid-term period, whereas the smallest change was recorded under RCP4.5 with near-term period. The finding clearly suggests that, the future climatic changes will have a major impact on crop water and irrigation water requirements of the selected crops in the study area. As a result, it is suggested that farmers, water managers, water user associations, and decision-makers work together to improve the current low level of water use efficiency by enhancing water storage, distribution, and use for crop production in the future.

Key Words: Climate Change; Emission Scenarios; Irrigation Water Requirements; Future Irrigation Demand; Gobu Seyo District

1. INTRODUCTION

Climate change is defined as a change in the condition of the climate that can be determined by changes in the mean and/or variability of its properties over time, usually a decade or more. Climate change can be caused by natural or external factors as well as chronic anthropogenic changes in atmospheric composition or land use.

For thousands of years, the world's climate has been changing, affecting both human and natural systems (Kotir, 2011; Birara *et al*, 2018). However, in recent decades, it has changed at a faster and more uncommon rate than in the past, as evidenced by rising temperatures, sea-level rise, increased greenhouse gas (GHG) emissions, frequent floods and droughts, and changes in the amount, distribution, and patterns of rainfall (Asarenuamah and Botchway, 2019). Despite the fact that climate change has a worldwide scope and influence, Africa has been designated as the continent most vulnerable to it due to low adaptive ability and a heavy reliance on climate-sensitive sectors like rain-fed agriculture (Conway and Schipper, 2011; Calzadilla *et al.*, 2013; Gebrechorkos *et al*., 2019; Girvetz *et al.*, 2019). The two most critical variables of climate change are regarded to be rainfall unpredictability and temperature warming, both of which have a devastating effect on agricultural output and long-term economic development in Africa, particularly in Sub-Saharan African (SSA) countries (Moss *et al*., 2010; Conway and Schipper, 2011; Calzadilla *et al*., 2013; Abera *et al.*, 2018; Gebrechorkos *et al*., 2019).

Ethiopia is one of the countries in Sub-Saharan Africa (SSA) that is particularly exposed to the effects of climate change and variability (Conway and Schipper, 2011; Birara *et al*., 2018). Recurrent droughts combined with changes in the amount and spatial distribution of seasonal and annual rainfall are among the major climate-related disasters in Ethiopia (Gleixner *et al*., 2017; Weldearegay and Tedla, 2018), thereby significantly affecting the productivity of rainfed agriculture and the economic and social development of the country.

Recurrent droughts, as well as changes in the amount and spatial distribution of seasonal and annual rainfall, are among Ethiopia's major climate-related disasters (Gleixner *et al*., 2017; Weldearegay and Tedla, 2018), negatively impacting rainfed agriculture productivity and the country's economic and social development.

Agriculture is Ethiopia's most important economic sector, accounting for about half of the country's GDP, more than 80% of employment, and 80% of foreign exchange earnings (Abera *et al*., 2020). Agriculture in Ethiopia is mainly reliant on natural rainfall, with just around 5% of total farmed land being irrigated (Awulachew and Ayana, 2011). With rising temperatures and evaporative requirements, the warming trend and climate variability have an impact on agricultural output. Climate change affects more than 95% of the crop output that is dependent on rainfall (Boru and Regassa, 2020). As a result, any change in rainfall amount or distribution would pose a serious danger to agricultural output, with urgent consequences for food production and security across the country.

Climate change affects irrigated crops as well as rainfed agriculture because irrigated crops are vulnerable to climate change. Climate change affects soil moisture during the growing season, as well as soil temperature and water content in the crop root zone during the non-growing season (Tan and Reynolds, 2013). It also affects crop yield, water demand, effective water supply, and availability for irrigation (Hanemann and Fisher, 2014).

For proper planning and decision-making, a good understanding of the temporal trends and spatial distribution of historical and projected rainfall and temperature is essential. As Ethiopia's government works to increase agricultural production, accurate and timely climate change data is critical for planning and developing appropriate mitigating methods.

With this, the overall goal of this study is to look at the effects of climate change scenarios on the irrigation water requirements of maize and wheat in Gobu Seyo District, East Wellega Zone, Oromia Region.

Materials and Methods

Description of the Study Area

Location

Gobu Seyo district is located in the Oromia Regional State of East Wollega Zone, 265 kilometers West of Addis Ababa and 65 kilometers from Zonal Town Nekemte. It is located at 9 °09 ′N and 36 °99 ′E, with elevations ranging from 1640 m to 1900 m above sea level.

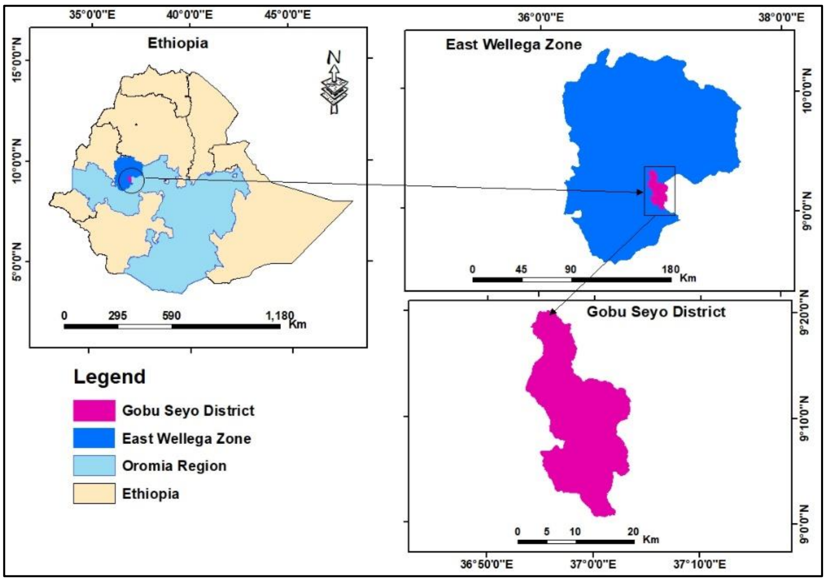

Figure 1. Location of Gobu Seyo district

Materials and Models

Materials

The following were among the materials used for this study: a digital camera for field photographs and core sampler, an auger, plastic bag, plastic hammer, reading gauge, timber, bucket, marker, data sheet, spatula, and double ring infiltrometer for soil sample and infiltration rate determination were among the materials used for this study.

Models

Ensembles of MarkSim-GCM model output for impact assessment, CROPWAT 8.0 model for crop water requirements estimation, Microsoft excel to compute double mass curve for consistency analysis and XLSTAT for homogeneity test and filling of missing rainfall data were used to achieve the study's goal.

Data Source and Collection

Meteorological data: Long-term meteorological data (1990-2019) was collected from Bako Agricultural Research Center.

Table 1. Location and data length of meteorological station selected

Station name	Data length	Latitude (º)	Longitude (º)	Elevation (m)
BARC	1990-2019	9.1	37.15	1650

Crop and soil data

Crop data files, including Kc values, stage days, root depth, and crop depletion fraction, were obtained from the FAO Irrigation and Drainage Division (FAO, 2012). Soil texture and bulk density were analyzed at Bako Agricultural Research Center and field capacity and permanent wilting point were determined at Engineering Corporation of Oromia laboratories at depths of 0-20, 20-40, 40-60, 60-80, and 80-100 cm.

Climate Model

Climate change scenarios generation

Even though there are numerous local climate data downscaling strategies for future period climate projections, the GCM run by MarkSim has lately been shown to be better and is used in many operations. This is especially true in Africa and Latin America (Jones and Thornton, 2013).

The ensemble average of the seventeen MarkSim-GCM atmosphere ocean climate models was used for two-time horizons of the 2020s (2023–2052) and 2050s (2053–2082) for RCP 4.5 and RCP 8.5 emission scenarios. Hence, to achieve the goal of this study future scenario climate data were downloaded from this web-based software tool by applying the aforementioned climate models accessed from http://gismap.ciat.cgiar.org/.

Data Required for CROPWAT Model

Reference evapotranspiration estimation

The FAO Penman-Monteith method is the only method for calculating reference crop evapotranspiration that is recommended (Allen *et al*., 1998).

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_m + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where: ET_O is Reference evapotranspiration(mm/day), Δ is Slope of the saturated vapor pressure curve (kPa °C^{-1}), R_n is Net radiation (MJ m^{-2} day^{-1}), G is Soil heat flux density (MJ m^{-2} day^{-1}), T_m is Mean air temperature (°C) at 2.0 m, U_2 is Average wind speed at 2.0 m height (m s^{-1}), es is Saturation vapor pressure (kPa) at temperature Tm, ea is Actual vapor pressure (kPa); ($es - ea$) is the vapor pressure deficit (kPa) and γ is Psychrometric constant (kPa °C^{-1}).

Computation of effective rainfall

Using the USDA method, effective rainfall was determined for the entire growing season and its appropriate crop stages (USDA, 1985) for both the base period and future periods.

$$P_{eff} = \frac{P_{month} * (125 - 0.2 * P_{month})}{125} \quad (5)$$

for $P_{month} <= 250$ mm

$$P_{eff} = 125 + 0.1 * P_{month} \text{, for } P_{month} > 250 \text{ mm} \quad (6)$$

Where: P_{eff} is Effective precipitation; P_{month} is monthly precipitation

Calculation of crop water requirements

Crop water requirements were estimated for both the baseline period and future scenarios based on the following equation (Allen *et al*., 1998):

$$ET_C = Kc * ET_O \qquad (7)$$

Where: ET_O is reference crop evapotranspiration, Kc is crop coefficient, and ET_C is defined as the evapotranspiration.

Irrigation Water Requirement

Irrigation water requirements (IWRs) were calculated knowing effective rainfall and crop water requirement. Allen *et al*. (1998) explained that IWR can be calculated from the difference between the crop water requirement (ETc, mm) and the effective rainfall (Pe, mm). The IWR is calculated by:

$$IWR = ET_c - P_e \qquad (8)$$

Where: P_e is effective rainfall (mm)

Results and Discussion

Climate Change Projection

Projected annual rainfall

Figure 2 shows the percentage change in mean annual rainfall for RCP 4.5 (2020s), RCP 4.5 (2050s), RCP 8.5 (2020s), and RCP 8.5 (2050s). From the annual rainfall analysis, the results revealed a decreasing trend from the baseline period through both the RCP 4.5 and 8.5 scenarios for each time period. There is a -9.28% and -8.69% decrease in mean annual rainfall from the base period to RCP 4.5 (2020s) and (2050s) respectively, and about -8.75% and -4.44% in RCP 8.5 (2020s) and (2050s) respectively. These findings are consistent with those reported by Birara *et al*. (2018).

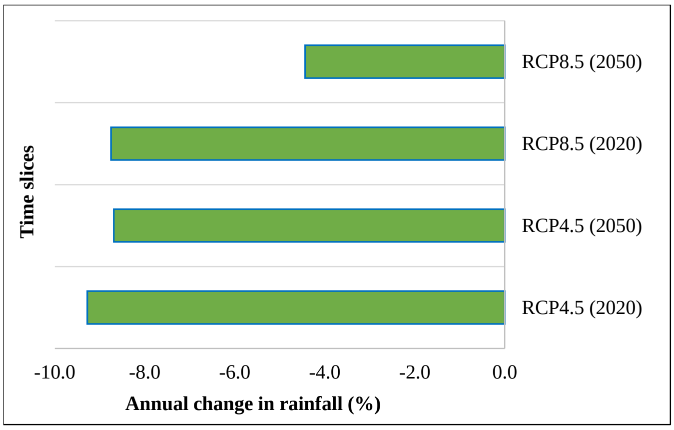

Figure 2. Projected percent change in annual rainfall under future scenarios

Projected annual maximum temperature

In terms of the mean annual maximum temperature (Figure 3), the change in mean annual maximum temperature under RCP4.5 (2020s) and RCP4.5 (2050s) ranges from 1.29 ºC to 1.89 ºC, with the highest change predicted for RCP4.5 (2050s) and the lower reported for RCP4.5 (2020s). While it ranges from 1.52 ºC to 3.03 ºC under RCP8.5, the largest was found under RCP8.5 (2050s) and the smallest was found under RCP8.5 (2050s). The result is also consistent with Bekele *et al*. (2019b) and Yadeta *et al*. (2020).

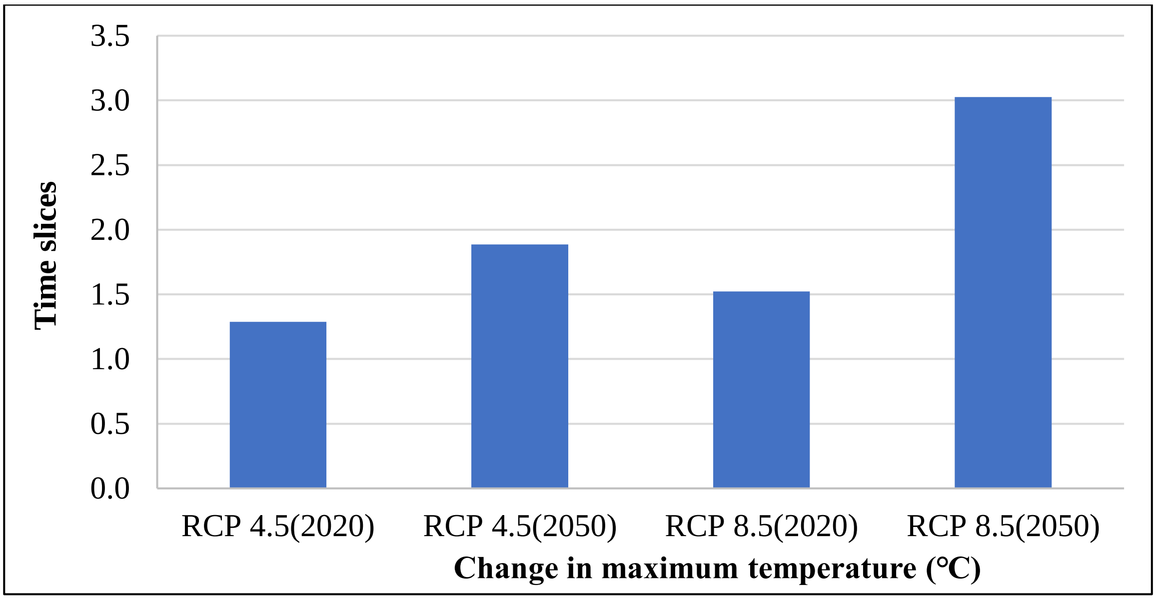

Figure 3. Projected change in annual maximum temperature under future scenarios

Projected annual minimum temperature

Regarding the mean annual minimum temperature (Figure 4), the change in mean annual minimum temperature ranges from 0.55 ºC to 1.37 ºC between RCP4.5 (2020s) and RCP4.5 (2050s), with the higher change occurring under RCP4.5 (2050s) and the lower occurring under RCP4.5 (2020s). While it ranges from 0.82 ºC to 2.48 ºC under RCP8.5, the largest was found under RCP8.5 (2050s) and the smallest was discovered under RCP8.5 (2020s). The greatest temperature variance in the location is higher than the minimum temperature variation. Conway and Schipper (2011) and Kassie *et al*. (2013) found similar results. According to Kassie *et al*. (2013), average temperatures in Ethiopia will climb by 0.8 °C in the 2020s and 1.2 °C in the 2050s.

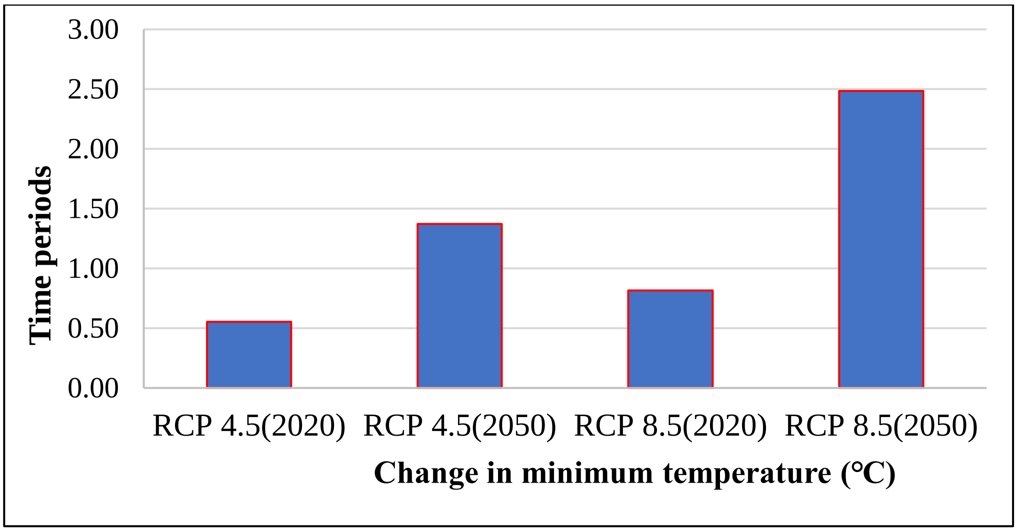

Figure 4. Projected change in annual minimum temperature under future scenarios

Crop Water and Irrigation Water Requirement under Current Climate

As illustrated in Figures 5 and 6, the crop water and irrigation requirements of maize and wheat crops were estimated for the baseline period. From the calculated crop water requirements under the baseline period, maize revealed the highest, and wheat has the lowest crop water requirement (Figure 5). For maize and wheat, it is 401.8 mm and 384.3 mm/growing time, respectively. In terms of irrigation water requirements, the similar circumstances were seen, with a maximum value of 263.1 mm/growing period for maize and a minimum value of 234.5 mm/growing period for wheat crop (Figure 6).

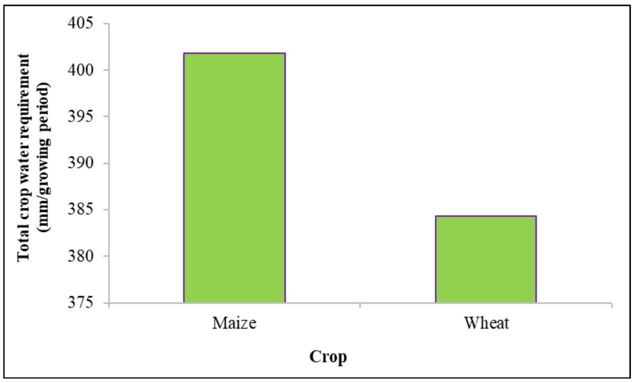

Figure 5. Total crop water requirement of selected crops under base period (1990-2019)

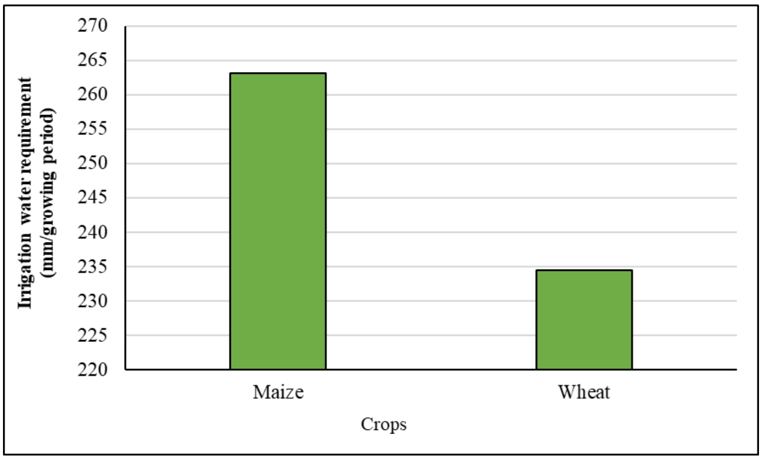

Figure 6. Total irrigation water requirement of selected crops under base period (1990-2019)

Implication of Climate Change on Crop Water and Irrigation Water Requirements

Changes in reference evapotranspiration (ET_O)

Figure 7 depicts an increasing yearly change in ET_O for both RCP4.5 and RCP8.5 across both time horizons of (2023-2052) and (2053-2082). RCP4.5 (2050s) shows greater yearly ET_O growth than RCP4.5 (2020s). RCP4.5 (2050s) had a +3.18% change in ET_O, whereas RCP4.5 (2020s) saw a +1.75% change. The ET_O trend was the same under RCP8.5 as it was under RCP4.5. RCP8.5 (2050s) had a higher increase of +5.37%, while RCP8.5 (2020s) had a smaller increase of +2.26% (2020s). This result shows that an increase in the time horizon also increases ET_O.

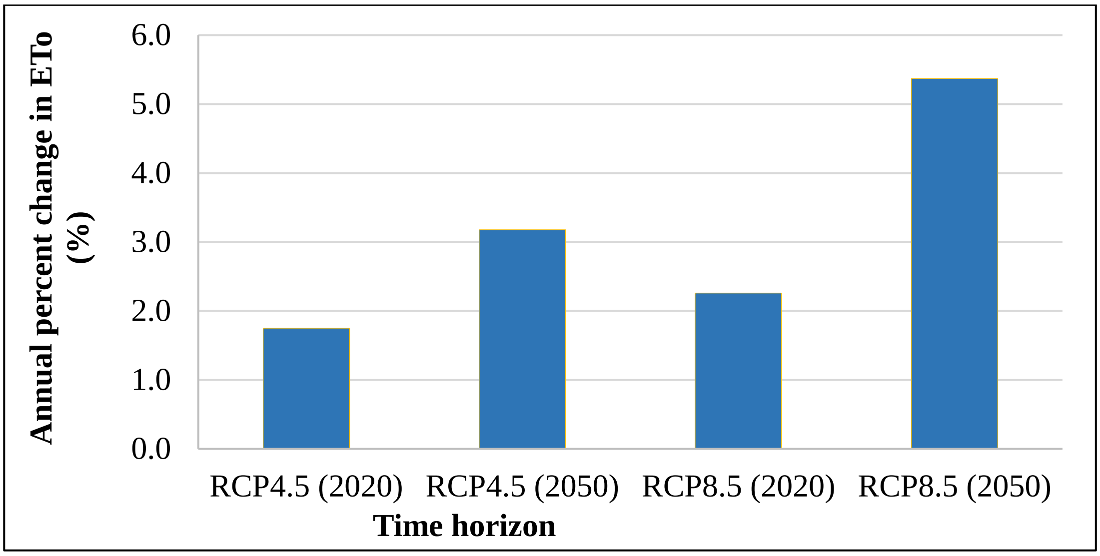

Figure 7. Annual change of reference evapotranspiration from base period (1990-2019)

Changes in crop water and irrigation water requirement of selected crops

As illustrated in Figures 8 and 9, the crop water and irrigation requirements of maize and wheat were estimated for the baseline period, as well as RCP4.5 and RCP 8.5 for both time slices. As a result, the change in maize crop water requirements ranged from 4.7% to 7.89% in both scenarios and time horizons (Figure 8). The change detected was highest in RCP8.5 (2050s) and lowest in RCP4.5 (2020s). From both the crops, wheat showed the greatest change in crop water requirements, which ranged from 4.55 to 7.78%, in which the highest change was detected under RPC8.5 (2020s) and the lowest was recorded in RCP4.5 (2020s). When comparing scenarios and time horizons, the higher emission scenarios and the greater distant period revealed a higher change in crop water requirements. This finding is in agreement with Bekele *et al*. (2019b), which states that the crop water requirement of maize crops under RCP4.5 and 8.5 is greater than the base period. It is also coincident with Tessema *et al*. (2017) and Boonwichai *et al*. (2018).

Regarding the irrigation water requirement, except under RCP4.5 (2020s), both scenarios along with time horizons revealed an incremental change in irrigation water requirement for both crops (Figure 9). Maize irrigation water requirement changes range from -1% to 3.9%, in which the decrement change was detected in RCP4.5 (2020s) and the highest increment was observed under RCP8.5 (2050s). Like maize, wheat also showed a decreasing trend under RCP4.5 (2020s) with a value of about -0.99% and revealed a maximum increasing trend with a value of 4.2%. This decrement is because of an increasing change in rainfall during the growing season of these crops. The result is similar to the study undertaken by Berhe *et al*. (2018). According to Boonwichai *et al*. (2018b), the average irrigation water requirements will increase in the future due to temperatures rise.

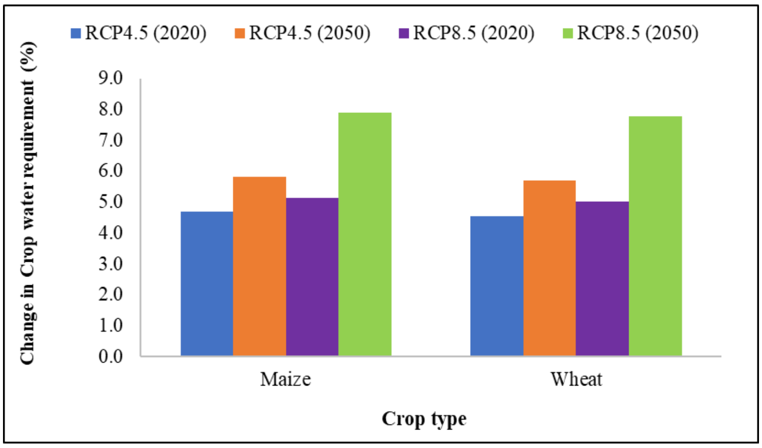

Figure 8. Change in Crop water requirement of major crops under future climate change

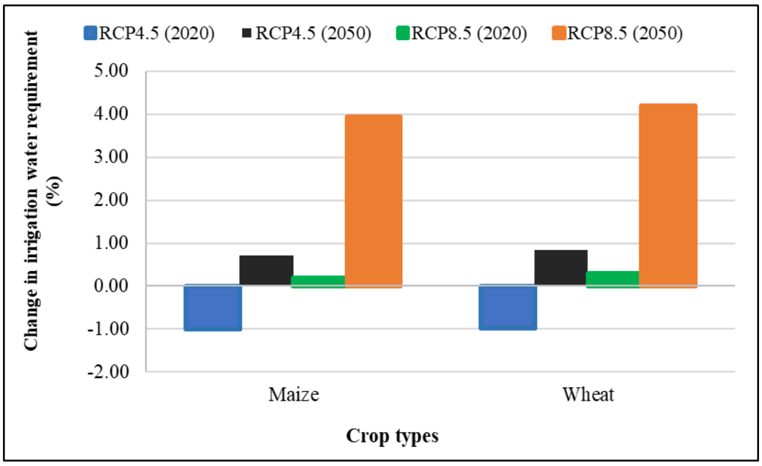

Figure 9. Change in irrigation water requirement of major crops under future climate change

Conclusions and Recommendations

This study aims to quantify the likely change in rainfall and temperature from the base period by the near and mid-future centuries and the possible implications of those changes on cop water and irrigation water requirements of the study area using the ensemble average of the seventeen MarkSim-GCM Atmosphere-Ocean climate models under two future scenarios.

Moreover, in annual rainfall, it decreased in both scenarios from the base period with a range of -4.44% to -9.28%, with a maximum decrement in RCP4.5 (2020s) and a minimum decrement in RCP8.5 (2020s).

Annually, the change in mean maximum temperature increased in each scenario and time horizon from the observed period. The highest and lowest of 3.03 ºC and 1.29 ºC of change in mean maximum temperature were detected under RCP8.5 (2050s) and RCP4.5 (2020s), respectively. Furthermore, the change of mean annual minimum temperature ranged from 0.55 ºC to 2.48 ºC, in which the maximum was recorded under RCP8.5 (2050s) and the lowest was recorded under RCP4.5 (2020s).

The crop water requirements of chosen crops were raised in the research area due to the expected impact of climate change. In both crops, RCP8.5 (2050s) showed the biggest change, and RCP4.5 (2020s) detected the smallest change. Except for RCP4.5 (2020s), irrigation water requirement showed an increasing trend in the future for each crop.

Generally, the future crop water use and irrigation water requirement of selected crops will increase in the study area. This is due to an increase in air temperature and a decrease in average rainfall in future years.

Recommendations

The following recommendation should be considered as superior alternatives and complementary activities for future crop and irrigation water and crop output in the study area.

- In order to boost climate-crop related research and develop adaptation strategies in Gobu Seyo district, institutional capacity for important data such as access to soil and crop databases should be built.
- According to the results of the study the maximum and minimum temperatures will increase in the future. Therefore, a number of climate change mitigation and adaptation strategies should be done in the study area.
- The increase in temperature and decrease in rainfall in Gou Seyo district have increased the water use rate of crops increasing the water stress that is now prevalent among crops. Given that situation more and more alternative irrigation schemes (small irrigation water collection structures), water harvesting techniques and application of soil water conservation techniques should applied in a study area.

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