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Climate Change Effects on Irrigation Water Requirements of Pepper and Potato at Gobu Seyo Wereda, Ethiopia

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Abstract: The need for irrigation water would be influenced by the fluctuating meteorological effects under the circumstances of climate change, and irrigation water will always represent the majority of water use in Gobu Seyo district. The purpose of the study was to look into how climate change would affect the amount of water needed to irrigate pepper and potatoes. The entire crop water consumption as well as the irrigation needs for the current and upcoming decades were modelled using the CROPWAT 8.0 software. In addition to the base period (1990-2019), forecasts for the future scenarios (2023-2052) and (2053-2082) were made using a MarkSim-GCM and the output ensemble of 17 GCMs for the medium (RCP4.5) and high (RCP8.5) emission scenarios. The analysis shows that in both scenarios (RCP8.5 and RCP4.5) and time periods (2023-2052 and 2053-2082), the agricultural water needs of both crops increased from 4.18% to 7.49%. The change in crop water requirements was highest for the mid-term period under the high emission scenario (RCP8.5), and the lowest for the near-term period under the medium emission scenario (RCP4.5). The range of the crops chosen for the research area's irrigation water requirements was 0.29% to 6.12%. While RCP4.5 with near-term time recorded the least change, RCP8.5 with mid-term period showed the most increasing change. The results strongly imply that the research area's chosen crops' water and irrigation needs will be significantly impacted by future climatic changes. In order to enhance the low level of water usage efficiency now in place, it is advised that farmers, water managers, water user associations, and decision-makers collaborate in the future to increase water storage, distribution, and crop output.

Keywords: Climate Change, Emission Scenarios, Irrigation Water Requirements, Future Irrigation Demand, Gobu Seyo District

1. Introduction

According to the definition of climate change, a change in the state of the climate can be identified by variations in the mean and/or variability of its characteristics over time, typically a decade or more. Chronic anthropogenic changes in the atmospheric composition or land use can all contribute to climate change, as can external or natural forces.

The global climate has been changing for thousands of years, impacting both natural and human systems [1]. Rising temperatures, sea level rise, increased greenhouse gas (GHG) emissions, frequent floods and droughts, and variations in the volume, distribution, and patterns of rainfall [2] show that it has altered more quickly and unpredictably than in previous decades. Africa has been identified as the continent most vulnerable to climate change due to its limited capacity for adaptation and substantial reliance on climate-sensitive industries like rain-fed agriculture [3, 4]. This is true even though climate change has a global scope and impact. Rainfall variability and temperature rise are considered to be the two most important aspects of climate change, and both have a catastrophic impact on agricultural productivity and long-term economic growth in Africa, particularly in Sub-Saharan African (SSA) nations [3, 5].

One of the SSA nations that is most vulnerable to the effects of climate change and variability is Ethiopia [1]. The most common climate-related disasters in Ethiopia [6, 7] include recurrent droughts along with variations in the quantity and spatial distribution of seasonal and annual rainfall. These disasters have a significant impact on the productivity of rainfed agriculture as well as the economic and social development of the nation.

Among Ethiopia's primary climate-related calamities [7], recurring droughts and changes in the quantity and spatial distribution of seasonal and annual precipitation have a detrimental effect on the productivity of rainfed agriculture as well as the nation's economic and social growth.

Ethiopia's largest economic sector is agriculture, which generates more than 80% of employment, half of the nation's GDP, and most of its foreign exchange earnings [8]. Only about 5% of the agricultural land in Ethiopia is irrigated, hence the country's agriculture is primarily dependent on natural rainfall [9]. The warming trend and climate variability have an effect on agricultural productivity due to rising temperatures and increased evaporative needs. More than 95% of crop output that depends on rainfall is impacted by climate change [10]. 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.

Because irrigated crops are more susceptible to climate change than rainfed agriculture, both are impacted by it. Climate change has an impact on soil temperature, water content in the crop root zone, and soil moisture during the growth season [11]. Crop output, water demand, effective water supply, and irrigation accessibility are also impacted [12].

Understanding the temporal trends and spatial distribution of past and anticipated rainfall and temperature is crucial for effective planning and decision-making. For planning and creating effective mitigating strategies, Ethiopia's government needs reliable and timely climate change data as it seeks to enhance agricultural productivity.

In light of this, the overall objective of this study is to investigate how several scenarios for climatic change may affect the amount of water needed for the irrigation of pepper and potato in Gobu Seyo District, Oromia Region, Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

Gobu Seyo district is situated in the East Wollega Zone of the Oromia Regional State, 65 kilometres from Zonal Town Nekemte and 265 kilometres west of Addis Abeba. Its coordinates are 9°09′N, 36°99′E, and it is between 1600 and 1900 metres above sea level.

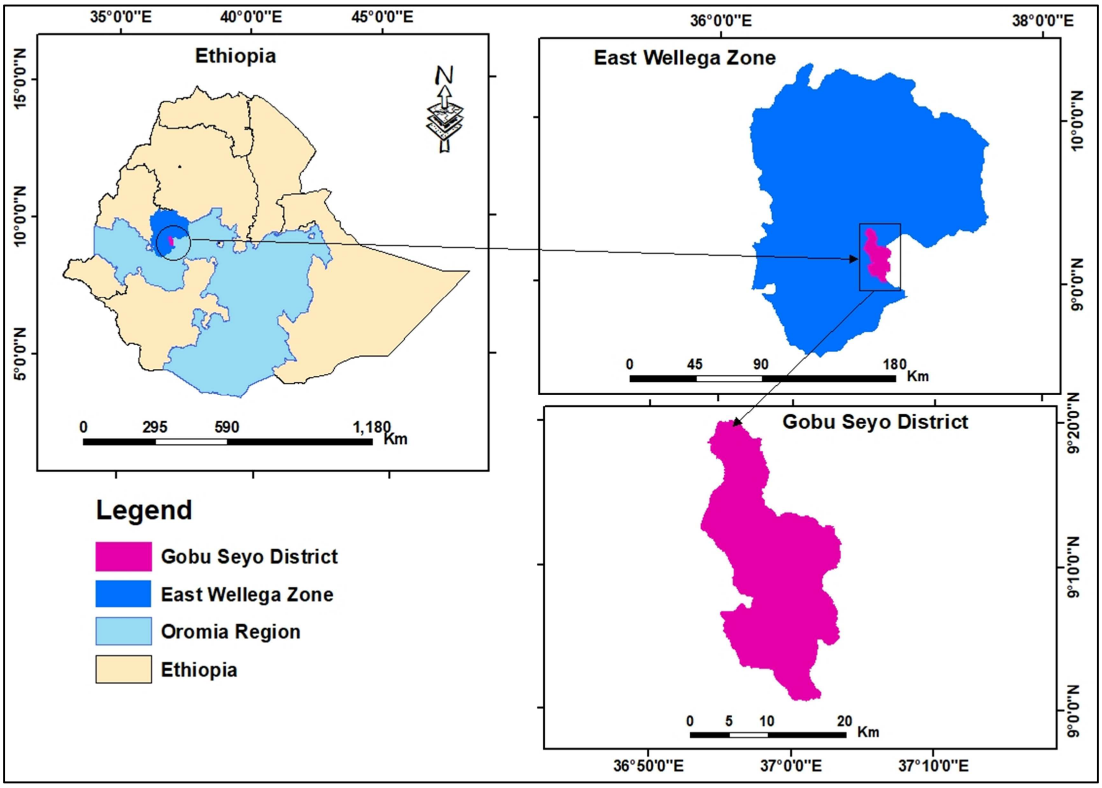

Figure 1. *Location of Gobu Seyo district.*

2.2. Materials and Models

2.2.1. Materials

The following items were used in this study: a digital camera for taking field photos, a core sampler, an auger, a plastic bag, a plastic hammer, a reading gauge, a piece of wood, a bucket, a marker, a data sheet, a spatula and a double ring infiltrometer for taking soil samples and figuring out infiltration rates.

2.2.2. Models

In order to accomplish the study's objective, ensembles of the MarkSim-GCM model output for effect assessment, the CROPWAT 8.0 model for crop water need estimation, Microsoft Excel to compute the double mass curve for consistency analysis, and XLSTAT for the homogeneity test and filling in the gaps in rainfall data were utilized order to accomplish the study's objective, ensembles of the MarkSim-GCM model output for effect assessment, the CROPWAT 8.0 model for crop water need estimation, Microsoft Excel to compute the double mass curve for consistency analysis, and XLSTAT for the homogeneity test and filling in the gaps in rainfall data were utilized.

2.3. Data Source and Collection

Meteorological data: The Bako Agricultural Research Centre provided long-term weather data (1990–2019).

Table 1. *Location and data length of meteorological station selected.*

Station name	Data length	Latitude (^{0})	Longitude (^{0})	Elevation (m)
BARC	1990-2019	9.1	37.15	1650

2.4. Crop and Soil Data

The FAO Irrigation and Drainage Division provided crop data files, which included Kc values, stage days, root depth, and crop depletion fraction [13]. Field capacity and permanent wilting point were assessed at the Engineering Corporation of Oromia laboratories at depths of 0-20, 20-40, 40-60, 60-80, and 80-100 cm, while soil texture and bulk density were examined at the Bako Agricultural Research Centre.

2.5. Climate Model

Climate change scenarios generation

The GCM operated by MarkSim has recently been demonstrated to be better and is employed in many operations, despite the fact that there are several local climate data downscaling methodologies for future period climate projections. This is particularly true in Latin America and Africa [14].

The RCP 4.5 and RCP 8.5 emission scenarios were applied to two-time horizons of the 2020s (2023-2052) and 2050s (2053-2082) using the ensemble average of the seventeen MarkSim-GCM atmospheric ocean climate models. Therefore, using the aforementioned climate models retrieved from http://gismap.ciat.cgiar.org, future scenario climatic data were collected from this web-based software tool to meet the purpose of this study.

2.6. Data for CROPWAT Model

Reference evapotranspiration estimation

The only technique for figuring the reference crop evapotranspiration that is advised [15] is the FAO Penman-Monteith approach.

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

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

Effective rainfall was calculated for the whole growing season and its relevant crop stages [16] using the USDA approach for both the base period and subsequent seasons.

$$P_{eff} = \frac{P_{month} * (125 - 0.2 * P_{month})}{125} \quad (2)$$

for $P_{month} <= 250$ mm

$$P_{eff} = 125 + 0.1 * P_{month}, \text{ for } P_{month} > 250 \text{ mm} \quad (3)$$

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

2.7. Calculation of Crop Water Requirements

Based on the following equation [15], crop water requirements were calculated for both the baseline period and potential future scenarios:

$$ET_C = Kc * ET_O \quad (4)$$

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

2.8. Irrigation Water Requirement

Knowing the effective rainfall and agricultural water requirements allowed for the calculation of irrigation water requirements (IWRs). According to Reference [15], IWR can be determined by subtracting the crop water demand (ETc, mm) from the effective rainfall (Pe, mm). IWR is determined by:

$$IWR = ET_c - P_e \quad (5)$$

Where: P_e is effective rainfall (mm)

3. Results and Discussion

3.1. Climate Change Projection

Projected annual rainfall

For the scenarios RCP 4.5 (2020s), RCP 4.5 (2050s), RCP 8.5 (2020s), and RCP 8.5 (2050s), Figure 2 displays the percentage change in mean annual rainfall. From the baseline era across both the RCP 4.5 and 8.5 scenarios for each time period, the yearly rainfall analysis results showed a decreasing trend. The mean annual rainfall decreases from the base period to RCP 4.5 (2020s) and (2050s) by -9.28% and -8.69%, respectively, and by around -8.75% and -4.44% in RCP 8.5 (2020s) and (2050s), respectively. These results are in line with those mentioned by [1].

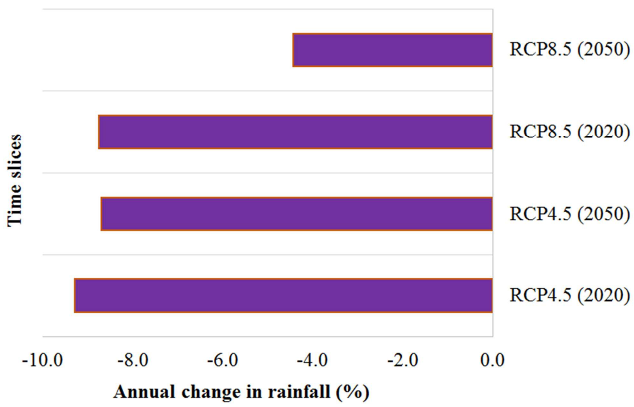

Figure 2. *Projected percent change in annual rainfall under future scenarios.*

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°C to 1.89°C with the highest change predicted for RCP4.5 (2050s) and the lower reported for RCP4.5 (2020s). While it ranges from 1.52°C to 3.03°C 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 [17] and [18].

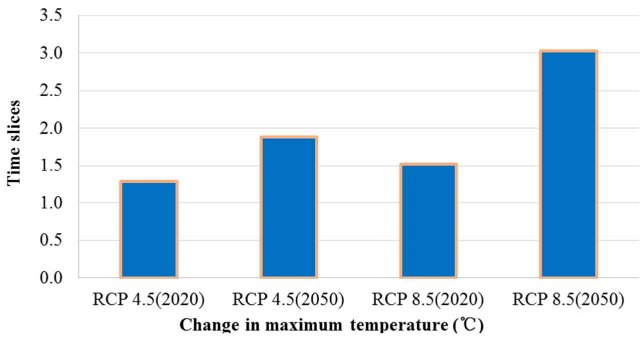

Figure 3. *Projected change in annual maximum temperature under future scenarios.*

Projected annual minimum temperature

Regarding the mean annual minimum temperature (Figure 4), the change in mean annual minimum temperature ranges from 0.55°C to 1.37°C 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°C to 2.48°C 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. Reference [19] and [20] found similar results. According to [20], average temperatures in Ethiopia will climb by 0.8°C in the 2020s and 1.2°C in the 2050s.

3.2. Crop Water and Irrigation Water Requirement Under Current Climate

The baseline period's estimated crop water and irrigation needs for the pepper and potato crops are shown in Figures 5 and 6. The potato crop had the greatest calculated crop water requirements during the baseline period, and the pepper crop had the lowest (Figure 5). It is 420.9 mm and 458 mm/growing period for pepper and potato, respectively. A maximum value of 293 mm/growing period for potatoes and a minimum value of 271 mm/growing period for pepper crops were observed for irrigation water requirements, respectively (Figure 6).

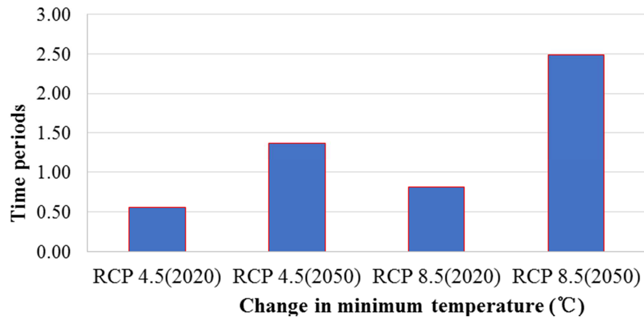

Figure 4. *Projected change in annual minimum temperature under future scenarios.*

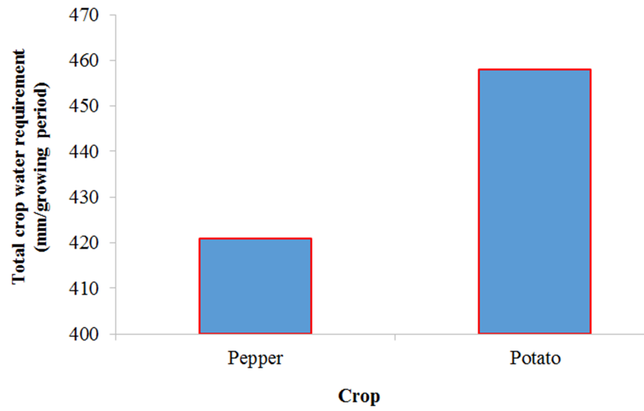

Figure 5. *Total crop water requirement of selected crops under base period (1990-2019).*

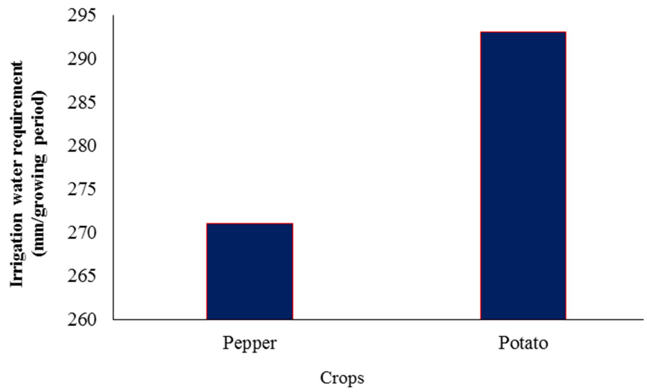

Figure 6. *Total irrigation water requirement of selected crops under base period (1990-2019).*

3.3. Implication of Climate Change on Crop Water and Irrigation Water Requirements

Changes in reference evapotranspiration (ET_O)

Figure 7 shows a rising annual change in ETO for RCP4.5 and RCP8.5 across the time horizons of (2023-2052) and (2053-2082), respectively. The annual ETO growth in RCP4.5 (2050s) is higher than in RCP4.5 (2020s). ETO changed by +3.18% in the RCP4.5 (2050s) and +1.75% in the RCP4.5 (2020s). Under RCP8.5 and RCP4.5, the ETO trend was same. While RCP8.5 (2020s) had a smaller increase of +2.26% (2020s), RCP8.5 (2050s) had a bigger increase of +5.37%. This outcome demonstrates that as the temporal horizon grows, so does ETO.

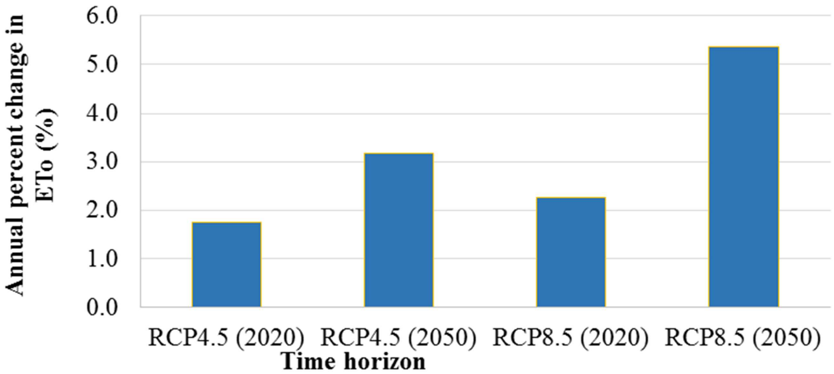

Figure 7. *Annual change of reference evapotranspiration from base period (1990-2019).*

Changes in crop water and irrigation water requirement of selected crops

The crop water and irrigation need for pepper and potato were calculated for the baseline era, as well as RCP4.5 and RCP8.5 for both time slices, as shown in Figures 8 and 9. As a result, across both situations and time frames, the change in pepper crop water requirements ranged from 4.19% to 7.49%. Additionally, in both scenarios and temporal periods, the variation in potato crop water requirements ranged from 4.18% to 7.47% (Figure 8). The change was most pronounced in RCP8.5 (2050s) and least pronounced in RCP4.5 (2020s). From the two crops, pepper's crop water requirements changed the most, with the maximum change being noted under RPC8.5 (2020s) and the lowest change being noted under RCP4.5 (2020s). When scenarios and time horizons were compared, the higher emission scenarios and the farther-off period showed a bigger shift in agricultural water needs. This result is consistent with [17], which claims that maize crops require more crop water under RCP4.5 and 8.5 than during the base era. It also occurs at the same time as [21] and [22].

As it can be seen, both scenarios and time horizons showed an incremental change in the irrigation water need for both potato and pepper crops (Figure 9). Changes in the amount of water needed for pepper irrigation range from 0.29% to 5.54%; the lowest change was found during RCP4.5 (2020s), and the biggest increase was found under RCP8.5 (2050s). Potato also demonstrated an upward tendency, ranging from 0.85% to 6.12%, with the lowest change being found during RCP4.5 (2020s) and the maximum change being seen under RCP8.5 (2050s). The outcome is comparable to the research conducted by [23]. Reference [22] predicts that as temperatures rise, the average amount of water needed for irrigation will also climb.

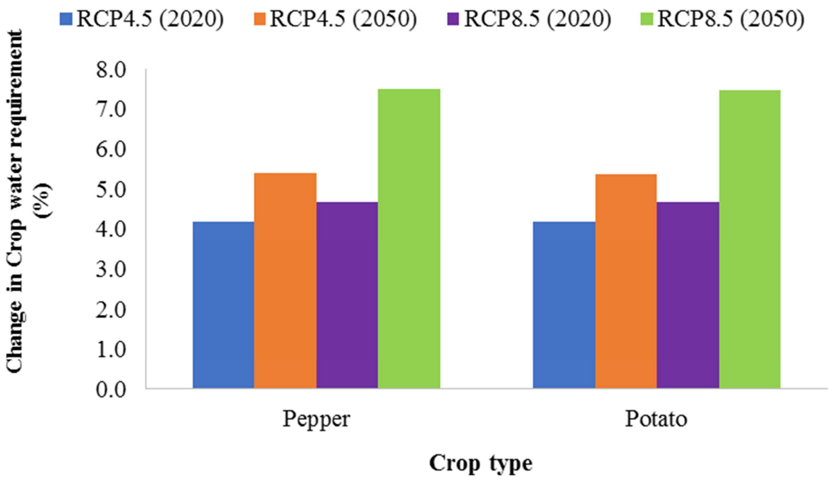

Figure 8. *Change in Crop water requirement of major crops under future climate change.*

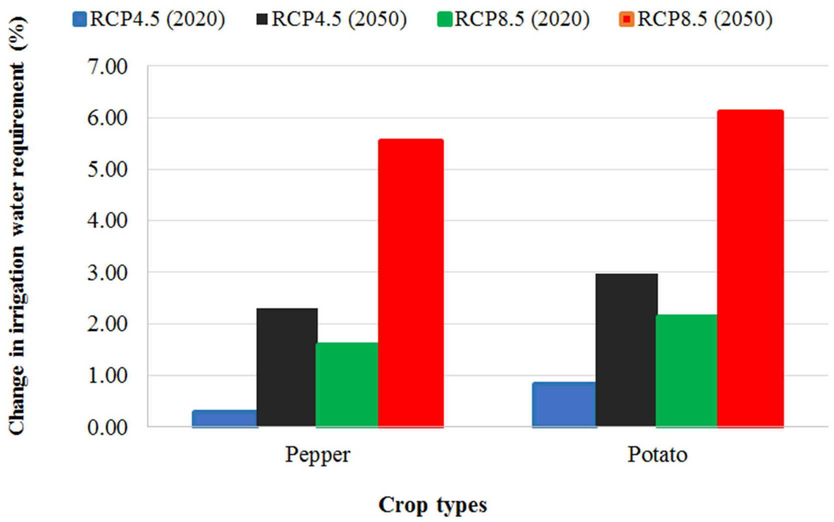

Figure 9. *Change in irrigation water requirement of major crops under future climate change.*

3.4. Conclusions and Recommendations

It is anticipated that long-term climate change will have an impact on crop production and the need for irrigation. The impact of long-term climate change may alter the irrigation water requirements of crops like pepper and potato, but this is not conclusively shown in study area. It is crucial to understand how long-term climate change affects important crops' irrigation water requirements since doing so facilitates the development of adaptation strategies.

Using the ensemble average of the seventeen MarkSim-GCM Atmosphere-Ocean climate models under two future scenarios, 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 potential implications of those changes on cop water and irrigation water requirements of the study area.

Additionally, yearly rainfall dropped in all scenarios from the base period with a range of -4.44% to -9.28%; the largest and minimum decreases were in RCP4.5 (2020s) and RCP8.5 (2020s), respectively.

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°C and 1.29°C 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°C to 2.48°C, in which the maximum was recorded under RCP8.5 (2050s) and the lowest was recorded under RCP4.5 (2020s).

The change in pepper and potato crop water requirements ranged from 4.19% to 7.49% and 4.18% to 7.47% respectively. Moreover, the changes in irrigation water requirements of both pepper and potato ranged from 0.29% to 5.54% and 0.85% to 6.12% respectively.

In general, projected crop water usage and irrigation water requirements of particular crops in the research area will rise. This is brought on by a rise in air temperature and a fall in annual rainfall averages.

4. Recommendations

The recommendations listed below should be taken into account as superior options and complementary actions for future crop and irrigation water use and crop yield in the study region.

1. Building institutional capacity for crucial data, such as access to soil and agricultural databases, is necessary to advance research on climate-related crops and to develop adaptation strategies in the Gobu Seyo district.
2. The study's findings indicate that future maximum and minimum temperatures will rise. As a result, the study region needs to implement a range of mitigation and adaptation methods for climate change.
3. In the Gobu Seyo district, the rise in temperature and decline in rainfall have raised agricultural water use rates and exacerbated the water stress that is now common among crops. Given this circumstance, a study region should implement an increasing number of alternative irrigation schemes (small irrigation water collection structures), water harvesting techniques, and soil water conservation strategies.

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