Impacts of Climate Change on Irrigation Water Requirement for the Major Grown Crop Production: a Case of Didesa Sub-Basin, Nile Basin of Ethiopia

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Research Article

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IMPACTS OF CLIMATE CHANGE ON IRRIGATION WATER REQUIREMENT FOR THE MAJOR GROWN CROP PRODUCTION: A CASE OF DIDESA SUB-BASIN, NILE BASIN OF ETHIOPIA

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Abstract

Natural and man-made activities in the sub-basin have influenced the climate change and induced the hydrology of the watershed . Changes in climate could affect metrological parameters, and thus the available water resource and which directly lead to changes in irrigation water requirement in agriculture. Therefore, this study was conducted to assess the current and future crop water use of major crops grown under climate change scenarios in the Didesa sub basin. For this study, daily metrological data such as maximum temperature, minimum temperature, wind speed, sunshine hours, and humidity and precipitation data were used. Crop and cropping pattern data were used for the study area. Future climate data predicted for the periods 2025, 2055 and 2085 considering both the A2 and B2 scenarios using GCM HadCM3. Crop evapotranspiration (ETo) was calculated using mean monthly climate and rainfall data with help of the CROPWAT 8.0. The crop water requirement (CWR) was determined for each crop in the project area of the study area for the baseline period (2020) and downscaled climate data. Crop water use of tomato crops increased from 1.2% and 1.4 % for H3B2 and H3A2 scenarios, respectively at 2085s. Similarly, sugarcane water requirement increased from 1.5% to 1.8% for H3B2 and H3A2 scenarios, respectively at 2085s. This increasing crop water requirement results in the crop water stress during scenario periods. Therefore, to solve water shortages, alternative sources of water supply such as ground water and water harvesting technologies should be studied and integrated water management systems should be implemented. In addition, to improve the efficiency of irrigation water, different irrigation methods such as drip irrigation should be improved in areas that have implication for driving climate change resilience as early warning.

Keywords: Didesa Sub-basin, Climate Change, Statistical Downscale Model, CROPWAT, Water Demand.

1. INTRODUCTION

Climate change is become a popular topic worldwide. It has an impact on the hydrological cycle and consequently on the available water resources and agricultural water demand. Changes in hydrological parameters due to climate change such as precipitation, temperature, runoff, stream flow and groundwater level, lead to not only changes in the crop water requirement in agriculture but also Hydropower, livestock environmental and industrial and domestic water consumption and demand will also change (Parekh and Prajapati, 2013; Geremew and Firaol, 2020).

Because of its geography and climate, Ethiopia has always been characterized by high hydrological variability, compounded by the almost total absence of water storage and highly vulnerable watersheds (World Bank, 2006). The Agriculture is the main source of livelihood for approximately 85% of Ethiopia's population and contributes. The warming trend and climate variability have an impact on crop production with increasing temperature and evaporative demand. Subsistent and small holder farmers who have less capacity to adapt to climate change produce more than 95% of crop production which is rainfall dependent has been affected by climate change (Geremew and Firaol, 2020; Tesema, 2019; MOFED, 2006; World Bank, 2006).

Ethiopia started to expand irrigation funded by international monitor fund with the aim of a growth transformation plan from agriculture to industry; which would narrow the current poverty. In addition to rain fed agriculture, climate change influences irrigated crops because irrigated crops are vulnerable to climate change directly or indirectly and also affect crop yield, water demand, effective water supply and availability for irrigation.

The Didesa sub-basin is one of the largest tributaries of the Abbay basin where Nile River emerge which is a trans- boundary river crossing many Africa countries such as; Ethiopia, Sudan, Kenya, Chad, Uganda and Egypt. Similarly, the Didesa sub-basin is one of the Blue Nile river basins which is characterized by agro-ecological climatic distribution (wet Dega, moist Dega, wet Weyna Dega, moist Weyna Dega and moist Kolla) and the production of cash and cereal crops such as (maize, potatoes, tomatoes, sesame, cotton, pepper, and wheat) practiced mostly on rain-fed crops and some of them by irrigation systems. However, both production systems are vulnerable to climate change which can affect crop growth and yield. Additionally, now a day in the sub-basin different irrigation projects are practiced, planned and started based on water availability in the sub basin ranging from small scale to large scale schemes to increase the income and food sufficiency of the people. In some irrigation schemes in the sub basin, climate change has a significant impact on crop yields (OIDA, 2017). Most of these schemes are traditional methods of water application. However, analysis of the effects of climate change on irrigated crop water use has not yet been analyzed. Hence, this study was designed to assess the current and future crop water use of major crops grown under climate change scenarios. This study contributes significantly to rain fed agriculture and driving climate change resilience as early warnings.

2. MATERIAL AND METHODS

2.1. Description of the study area

According to **Figure 1** The Didesa sub-basin is mainly located in the East and West Welega, Illubabor, Jimma of the Oromiya region and some parts of Kamashi in Benishangul-Gumuz. Geographically the sub-basin is located between 07040'- 1000N and 35032'-37015'E latitude and longitude respectively in western part of Ethiopia (Legese et al., 2015). The general elevation in the basin ranges between 653 m a.m.s.l. and 3144 m a.m.s.l

The Didessa River, which is the largest tributary of the Blue Nile (Abay), contributes approximately a quarter of the total flow of the Blue Nile. The total catchment area drained by the river is estimated to be 28,229 km2 originating from the mountain range of Gomma in Southwestern Ethiopia. The mean annual rainfall in the study area was approximately 1745mm. Most of the area is characterized by a humid tropical climate with heavy rainfall and most of the total annual rainfall is received during a rainy season called kiremt. The maximum and minimum temperatures vary between 21.3 – 30.90C and 10.9 - 15.10C, respectively.

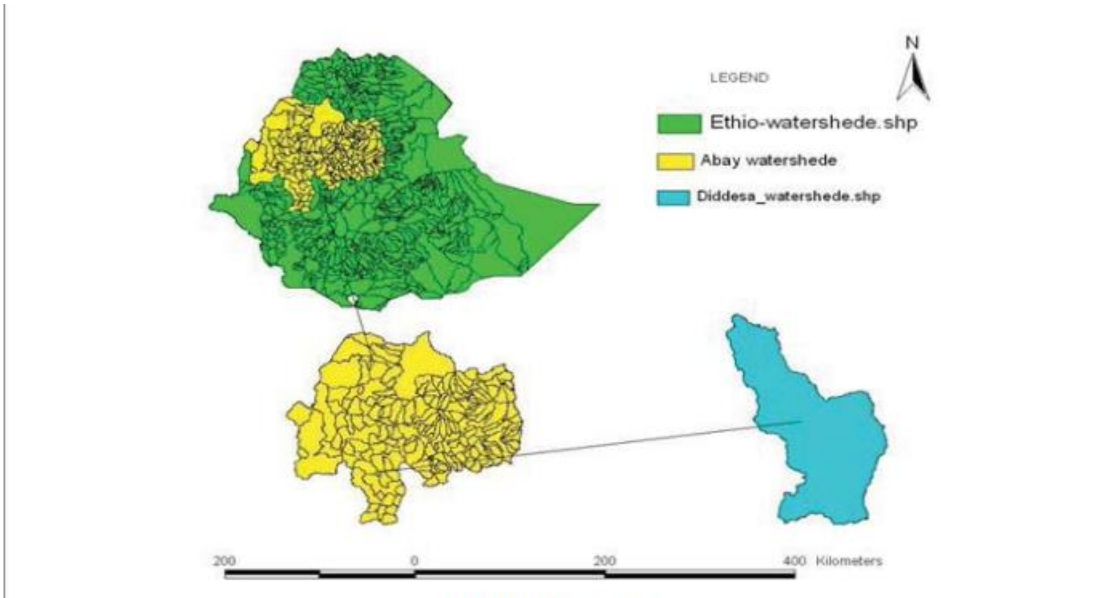


Figure 1: Map of the study area.

(Source Legese et al., 2015)

Figure. 1 map of study area

2.2. Data used and data analysis

Historical climate data required for the analysis were collected for approximately 29 year (1992-2020) from five agro climatic zones. These are wet Dega, moist Dega, wet Weyna Dega, moist Weyna Dega and moist Kolla. The maximum and minimum temperatures vary between 21.3 – 30.90C and 10.9 - 15.10C, respectively. It has a uni-modal rain fall distribution.

2.3. Future data Set

NCEP reanalysis Data: National center of Environmental Prediction (NCEP) of 2.50 latitude X 2.50 longitude grid- scale re-analysis data are obtained from the Canadian Climate Impacts Scenarios (CCIS) website for a period of 41 years (1961-2000).

GCM Data: The large-scale Hadley Center's GCM (HadCM3) for (HadCM3) A2 and B2 future scenario data of 3.750 latitude by 3.750 longitude grid-scale for the period of 139 years (1961-2099) were obtained from the Canadian Climate Impacts Scenario (CCIS) website) (http://www.cics.uvic.ca/scenarios/sdsm/select.cgi). HadCM3 was chosen because of its wider acceptance of the impacts of climate change. Daily predictor variables from HadCM3 used for the SDSM Model.

2.4. Crop water use estimation

In this study the crop water requirements for crop types and cropping patterns were estimated using the CROPWAT software. CROPWAT uses FAO Penman-Monteith model for estimating reference evapotranspiration. FAO Penmann-Monteith Model to estimate the reference evaporation:

$$\boldsymbol{Eto} = \frac{\mathbf{0.408}\Delta(\boldsymbol{Rn}-\boldsymbol{G})+\boldsymbol{\gamma}\frac{\mathbf{900}}{\boldsymbol{T}+\mathbf{273}}\boldsymbol{u}\mathbf{2}(es-ea)}{\Delta+\boldsymbol{\gamma}(\mathbf{1}+\mathbf{0.34}\boldsymbol{u}\mathbf{2})}$$

Where Rn is the net radiation, G is the soil heat flux, (es - ea) represents the vapour pressure deficit of the air, Δ represents the slope of the saturation vapour pressure temperature relationship, ɣ is the psychrometric constant. ETo is the reference evapotranspiration (mm/day), u2 wind speed at 2 m height (m/s), es saturation vapour pressure (kPa), ea actual vapour pressure (kPa).

According to Table 1 the crop water requirement for each crop in the command area has been based on the crop coefficient (Kc) and estimated ET0

$$\mathrm{ETc} = \mathrm{Kc} * \mathrm{ETo}$$

Where, Kc is crop coefficient,

The crop water use of major grown crops was then derived through a crop coefficient that integrated the combined effects of crop transpiration and soil evaporation into a single crop coefficient (Kc), based on the following relationship (Mohan and Ramsundram, 2014; MOA, 2011; FAO, 1984).

Table 1 Growth stages and crop coefficients of selected major irrigated crops in the sub-basin

No.	crop	Growth stages				Crop coefficient			
1	wheat	Initial	Dev't	Mid	Late				
		30	30	40	30	0.30	1.15	1.15	0.75
2	sugarcane	30	60	180	95	0.40	1.25	1.25	0.75
3	maize	20	35	40	30	0.3	0.7	1.2	0.8
4	cabage	40	60	50	15	0.48	0.8	1.1	0.9
5	tomato	30	40	45	30	0.5	0.7	1.15	0.80
6	potato	25	30	45	30	0.5	0.75	1.1	0.9

(Source: MOA, 2011; FAO, 1984)

2.5. Impact assessment analysis

The crop water use for the selected irrigated crops grown in the study area was estimated from observed and downscaled future climate data. The impact of climate change on the irrigation water requirements of these selected crops was determined for a monthly time step. For both the H3B2 and H3A2 scenarios, the calculated irrigation water use is averaged in to monthly in for the scenario of the current and future time periods, namely 2025, 2055 and 2085. Finally, the projected average of irrigation water use was subtracted from the corresponding average monthly irrigation water use of the base line time period which is calculated from *FAO* Penman-Monteith equation .

The irrigation water demand was calculated based on the irrigated crops in the sub-basin. Climatic data used for calculating the irrigation water requirement of the major grown crops were selected depending on the agroecological zones and the mean areal area of climatic data was used. According to MOWIE (2020) and OIDA (2017) the existing and planned schemes for irrigation including large to medium irrigation: one on the Didesa river and one on each tributary, the Dabana and Negeso rivers to irrigate 55,000 ha and small irrigation projects situated in the Didesa sub-basin are categorized under Didesa agricultural water demand estimation. A total land area of 85,000 ha covered by small to large irrigation projects in the study area was proposed to be irrigated by different crops during full irrigation. However, to determine the irrigation water requirement of all crops over the entire Didesa sub-basin, water requirement m^3 per hectare for each crop was taken from the feasibility study of Didesa irrigation project.

3. RESULT AND DISCUSSION

3.1. Future Scenario Generation

The HadCM3 predictor variables derived from the NCEP dataset using Multiple Linear Regression Models between the predictand and large-scale predictors were used to generate future downscaled data for the A2 and B2 scenarios. Downscaling process was conducted for the current and future time periods, namely 2025, 2055 and 2085. The results of the downscaled mean daily rainfall and, maximum and minimum temperatures for different periods are shown in **Fig 2** for scenarios A2 and B2.

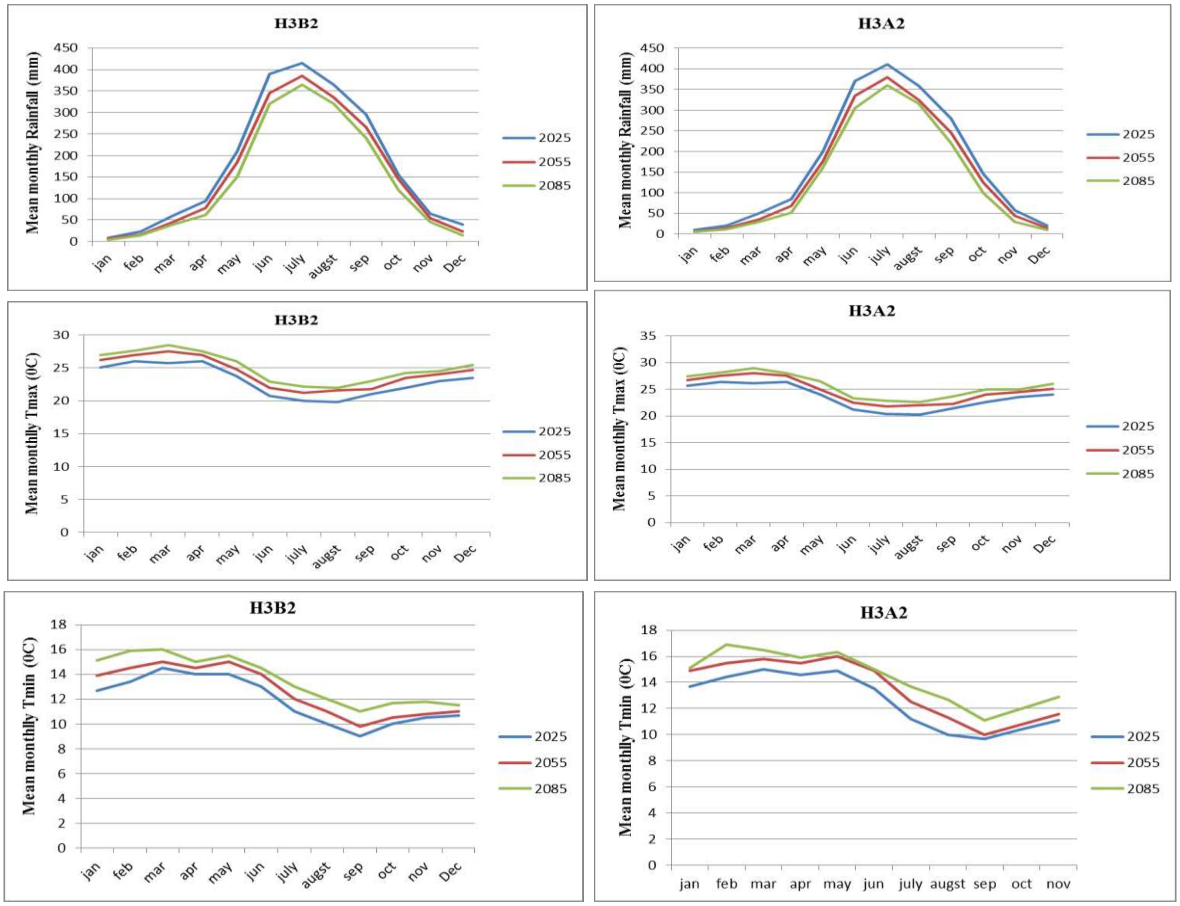


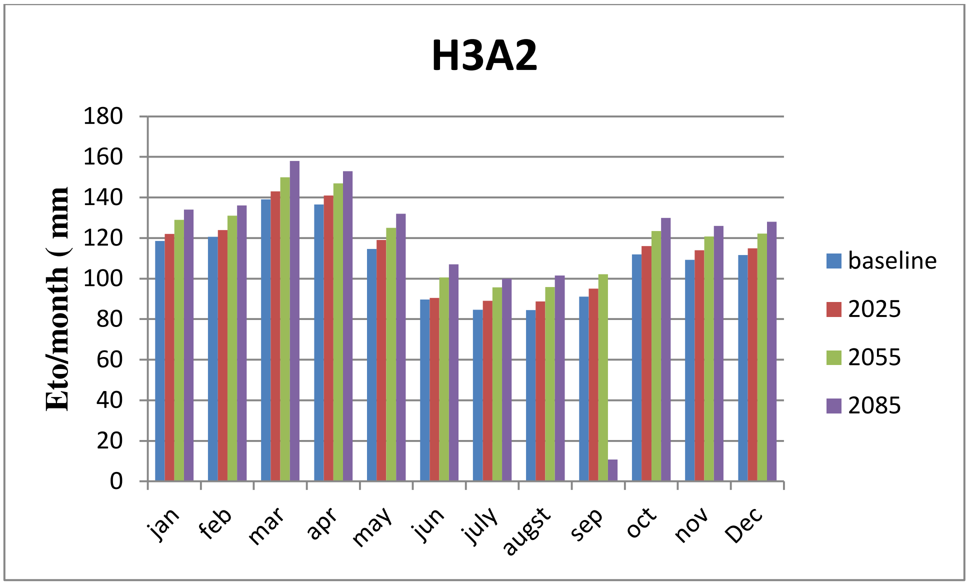
Figure 2 general trend of mean monthly rainfall. Min temperature and maximum temperature for different period corresponding to HadCM3 A2 and B2

The figures show that the mean monthly rainfall does not show a constant increase or decrease in rainfall trend except in July for the both scenarios of the current and future time periods whereas the mean monthly temperature increases in both scenarios except for the June month for the minimum temperatures of 2055 and 2085 for the A2 scenario. The results show that there is an increase in the trend of for future annual precipitation for the periods 2025 and 2055 for both the A2 and B2 scenarios compared to the 2085 scenario. In 2025, the simulated rainfall was 2025 mm and 2122 mm for scenarios A2 and B2, respectively. Similarly for 2055, 2085, the annual mean precipitation was 1767 mm, 1599 mm for A2 and 1885 mm and 1694 mm for B2 respectively. In general there was increase in temperature and decrease in rainfall for both scenarios, and we can conclude that decrease in rainfall is due to increase in minimum and maximum temperature under the Didesa basin.

3.2. Estimation of future reference crop

Reference evapotranspiration (ETo) was estimated for base period and future climate scenarios periods (2025s, 2055s and 2085s) by downscaled future climate data (Figure 3). The result shows that at the baseline period ETo varies in the range of 84.53 to 139 mm/month in the sub basin. The ETo increases gradually from approximately 84.53 mm/day in August to the peak value of about 139 in March due to hot temperature and low rainfall in this month.

The minimum and maximum ETo was predicted to be in the range of 86.– 141 mm/month at 2025s, 90.7- 147 mm/month at 2055s and 96– 154.5 mm/month at 2085s under H3B2 scenario (Figure 3) while in the sub-basin the minimum and maximum ETo was observed in August and March respectively having (86 mm/month) magnitudes at 2025s and (154.5 mm/month) magnitudes at 2085s (Figure 3). Change in ETo at 2085s was high as compared with 2025s and 2055s due to increasing temperature and significant decreasing of rainfall over the study area in both HadCM3's.



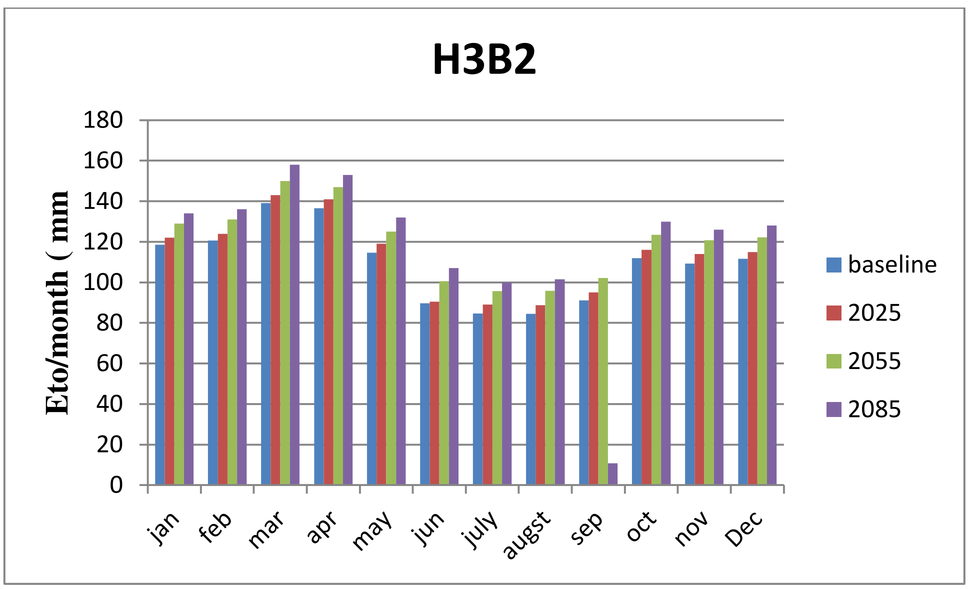


Figure 3 Evapotranspiration (ETo) at base period, 2025s, 2055s and 2085s scenario periods of the study area corresponding to H2M3 A2 and B2 scenario

The analysis reveals that annual potential evapotranspiration are predicted to increase with increase in temperature. The average projected annual reference crop evapotranspiration increase with 1.44 % 2025s, 5% 2055s and 9% at 2085s in the sub basin for H3B2 scenario. Similarly, the projected annual ETo increase by 2% in 2025s , 9.8% in 2055s and 11% in 2085s in Didesa sub-basin under H3A2 scenario. The seasonal ETo increases over the sub-basin and the highest increase were observed in bega seasons in future. This result is supported by (Enyew et al., 2014; Gebre, 2015 and Mekonen, 2013) that at the end of the 21st century potential evapotranspiration was increase in all months of the year.

3.3. Future water requirement of selected major grown crops

Crop water use estimation was carried out for different climate change scenarios and scenario period and the result was shown in (figure 4, 5 and 6) below. The result reveals that crop water requirement increases in the future for all major crops grown(wheat, Maize, Tomato, potato, Cabbage and sugarcane) as compared to baseline period due to increasing temperature as well as evapotranspiration over the study area (Table 2). In the period 2025, 2055s and 2085s, cabbage shows increment in crop evapotranspiration by 0.15% and 0.3%, 0.56% and 0.8%, 1% and 1.26% for H3B2 and H3A2 scenarios respectively. Similarly, crop evapotranspiration of maize may increase by 0.2% and 0.3%, 0.6% and 0.7%, 0.9% and 1.13% at 2025s, 2055s and 2085s respectively for H3B2 and H3A2 scenarios. Water requirement for potato crop are 0.25% and 0.3%, 0.9% and 1%, 1.2% and 1.3% at 2025s, 2055s and 2085s, respectively for H3B2 and H3A2 scenarios. sugarcane water requirement increased by 0.2% and 0.3%, 0.8% and 1%, 1.5% and 1.8% at 2025s 2055s and 2085s respectively for H3B2 and H3A2 scenarios. In similar way, tomato water requirement increase ranges from 0.2 and 0.2%, 0.95% and 1.1%, 1.2% and 1.4% for both scenarios H3B2 and H3A2 scenarios. wheat water requirement increased by 0.3% and 0.3%, 0.8% and 1%, 1.1% and 1.3% at 2025s 2055s and 2085s respectively for H3B2 and H3A2 scenarios during three time slices over the Didesa sub-basin.

Table 2 Total water requirement during growth stages and percentage changes under climate change of the selected crops in Didesa sub-basin

		Total CWR (mm/growth period)						Percentage (%) change per growth period					
crop	baseline	2025		2055		2085		2025		2055		2085	
		H3B2	H3A2	H3B2	H3A2	H3B2	H3A2	H3B2	H3A2	H3B2	H3A2	H3B2	H3A2
Cabbage	610.1	611	612	613.3	615	616.5	617.8	0.15	0.3	0.56	0.8	1	1.26
Wheat	391.9	392.5	392.7	393.5	395	395.3	397	0.3	0.3	0.8	1	1.1	1.3
Sugarcane	1333.5	1336	1338	1343	1347.8	1352	1357	0.2	0.3	0.8	1	1.5	1.8
Maize	406.4	407	406.8	407.5	408	409.5	411	0.2	0.3	0.6	0.7	0.9	1.13
Tomato	542.5	543	543.7	546.5	547	548.5	550	0.2	0.2	0.95	1.1	1.2	1.4
Potato	467	467.6	467.8	469	470.5	471	473	0.25	0.3	0.9	1	1.2	1.3

(Source: own work)

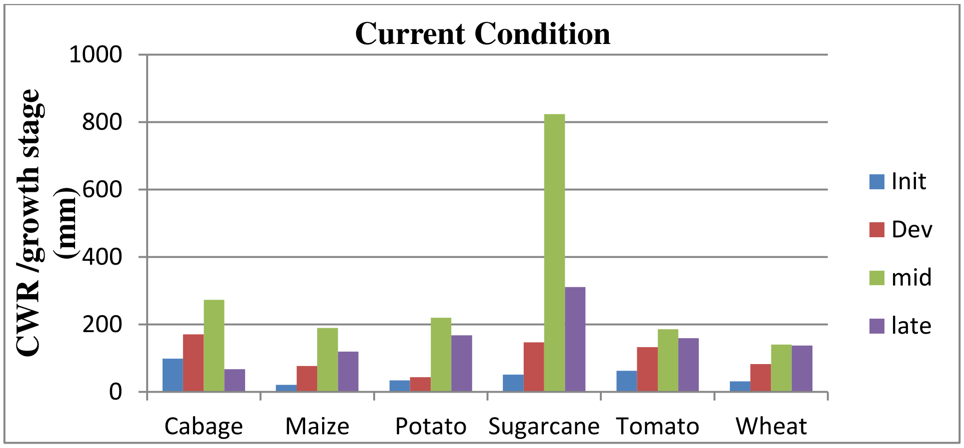


Figure 4 Crop water requirement of major grown crops at baseline periods in Didesa sub basin

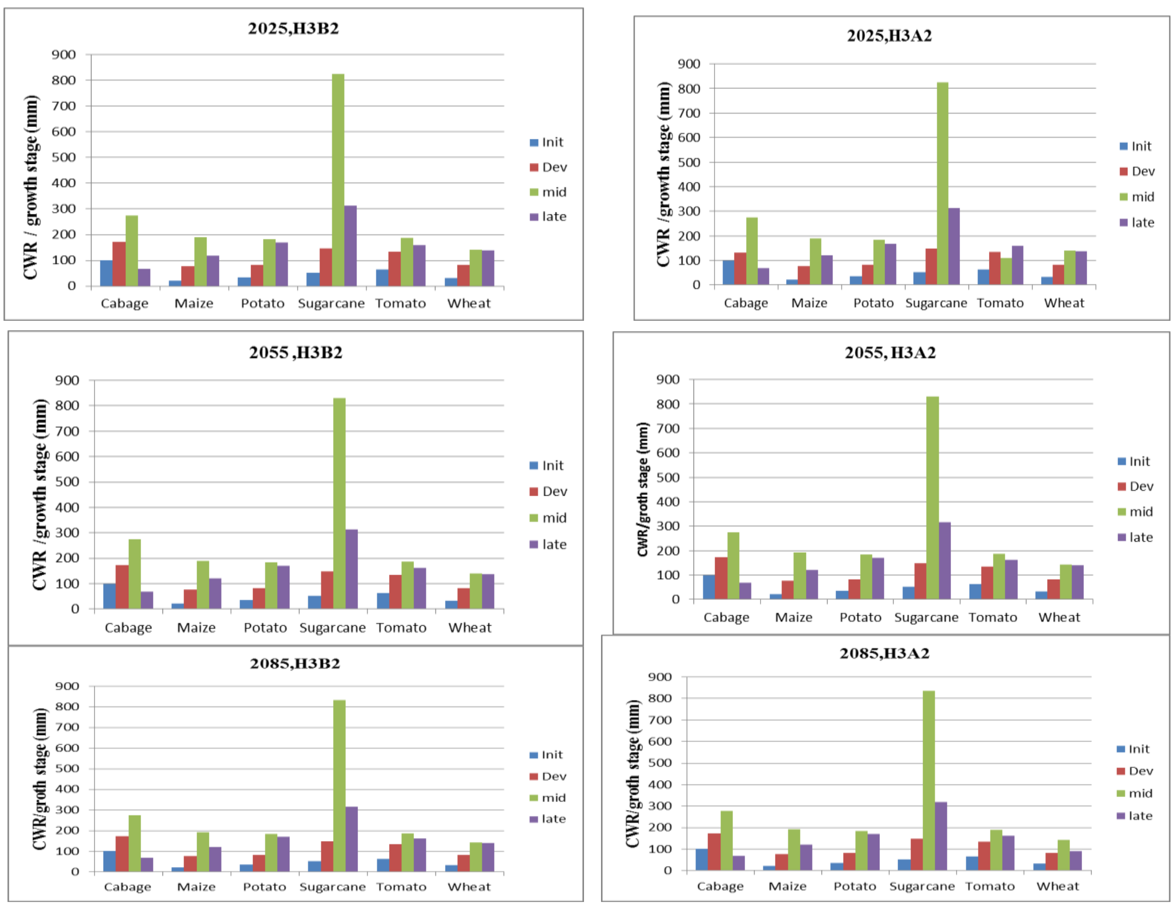


Figure 5 crop water requirement of major irrigated crops over Didesa sub basin 20205s, 2055s, 2085s during full irrigation under H3A2 and H3B2 Scenarios

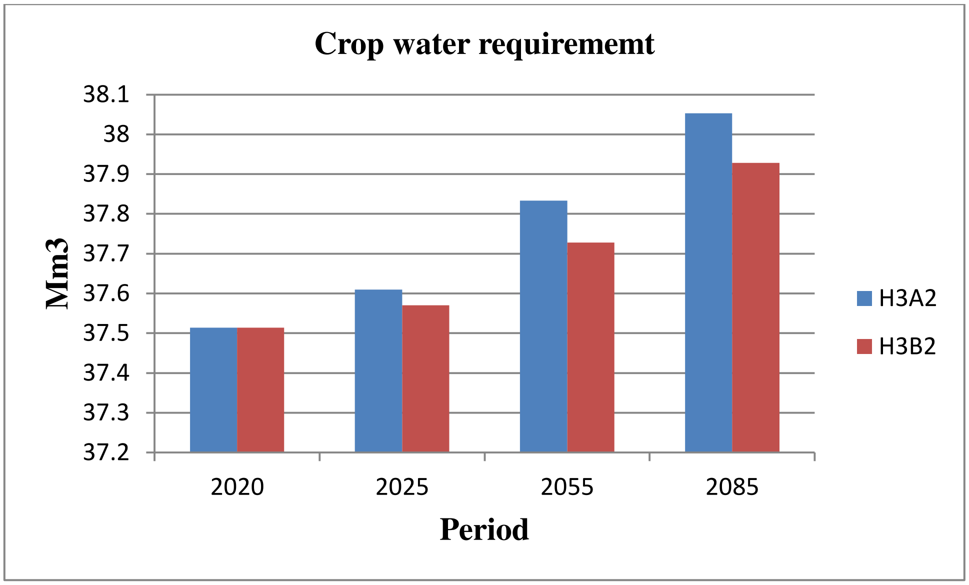


Figure 6 crop water requirements for different period corresponding to HadCM3 A2 and HadCM3 B2 scenario

The total Crop water requirement for different period corresponding to HadCM3 A2 and HadCM3 B2 scenario was slightly increasing due to increase in temperature and thus increase in Eto. In all periods crop water requirement is slightly higher in HadCM3 A2, 37.832 Mm3 when compared to HadCM3B2, 37.3 Mm3. In general future water requirement is increasing for all time period in both scenarios when compared to the base line scenario.

4. CONCLUSION

Estimation of Irrigation water demand is necessary for agricultural production and Thus, Food self-sufficiency and poverty reduction. Due to the increase of temperature the rate of evapotranspiration would increase which directly increase the rate of crop water use. Thus, the result shows that crop water use of the major grown crops were higher at the mid stage than others both at baseline and scenario periods. The crop water use of tomato crop increased from 1.2% and 1.4% at 2085s, for H3B2 and H3A2 scenarios, respectively. Similarly, sugarcane water requirement increased from 1.5% to 1.8% at 2085s for H3B2 and H3A2 scenarios, respectively. In all periods crop water requirement is slightly higher in

HadCM3 A2, 37.832 Mm3 when compared to HadCM3B2, 37.3 Mm3. This increasing crop water requirement results crops water stress in scenario periods. In response to such condition some water management and adaptation were required to reduce water consumption by crops based on crop varieties that has short growth period, water stress tolerant crops and providing new varieties especially of Wheat, potato, tomato, maize, cabbage and sugarcane which could resist high evapotranspiration under changing climatic condition.

The results of this study should be taken with care taken for only tomato and sugarcane crops to be brought new verities of drought resistant crops and also the study general recommend the expansion of irrigation projects for food self-sufficiency for Ethiopian farmers as well as for the nations income as the whole. Additional, it is also necessary for policy makers and planners of water resources for future and suggest that water saving techniques are required to satisfy increasing crop water use under scenario periods.

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Conflict of interest

The authors declares there is no conflict of interest to disclose

Data Availability Statement

This study did not receive any funding in any form.

Funder

Ethical consideration

There is no human as well as animal experiment in this article.

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