Impact of Climate Change on net Irrigation Water Requirement of major crops in the semi-arid regions of Northern Ethiopia

Babak Mohammadi

Department of water engineer, Agriculture faculty, University of Tehran, Babakmsh@yahoo.com

Abstract: Climate change (CC) and variability are a serious threat to crop production in the semi-arid areas of Northern Ethiopia. Understanding the impact of CC on irrigation water requirement (IWR) of crops is essential for water managers and producers to understand its impact and devise adaptation measures that must be taken ahead of time. In this study, CropWat model was used to study the impact of CC on Maize and Onion IWR in the semi-arid region of Ethiopia. Downscaled CC data from global climate models (GCMs) and emission scenarios, Representative Concentration Paths (RCPs): RCP_4.5 and RCP_8.5 were used as an input to CropWat model and develop projections of IWR in the 2045-2074 and 2075-2100. The findings showed that CC will significantly change net IWR of the crops in the next 86 years. Considering the mean ensembles of all GCMs in the 2075-2100 and under RCP_8.5, net IWR was projected to increase by 12% comparing to the baseline scenario (1985-2014) for both crops. In the case of 2045-2074 and under RCP_4.5 projections, net IWR of both crops was projected to increase by 6%. This result explicitly shows that availability of irrigation water in the region and other similar areas of the country will be the main constraints to expanding irrigated agriculture in the future. The authors of this study would like to recommend farmers, water managers, water use associations and decision makers in the region should work towards improving water use efficiency in the future.

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1. Introduction

Climate change and variability today are a serious threat to crop production in Ethiopia generally and in Tigray region particularly. A marked increase in both scale and frequency of drought has become apparent over the last decades in the country (Demeke et al. 2011). Climate extremes, such as drought and floods that have affected the region frequently and accordingly, it is known to be one of the drought prone areas in the country where crop failure due to moisture stress is estimated up to 40% (Hailemichael 2003). The region has suffered from frequent droughts in the past 35 years. For example in 1982, 1983, 1984, 1985, 1987, 1991, 1999, 2000, 2002, 2004 and 2009 (Gebrehiwot et al. 2011). Moreover, the sensitivity of the region to climate variability was demonstrated by a devastating drought during 1888-1892 and 1988-1995 where the people in the region were starved, died and displaced to the Republic of Sudan (Gebrehiwot et al. 2011; Legesse et al. 2003). Considering the fact that more than 85% of the Tigray population are dependent on agriculture (Hailemichael, 2003) and the sector is under significant climate stress, climate change and variability could hamper poverty reduction efforts that have been undertaken in the region in particular and in the country in general.

The farmers of the region have been suffering from water scarcity and moisture stress and the crop yield has been severely affected during part of its growing period (Araya and Stroosnijder 2010). To alleviate such problems, many water storage infrastructures including, small water tanks, micro dams, and river diversions have been constructed in different parts of the region since 1991 (Haregeweyn et al. 2006; Hagos 2005). Although these initiatives gave promising results on crop production, still the future of crop production with a given limited amount of water resource and under climate change is not certain. Investigating the likely impacts of future climate change on irrigation water requirement of the major crops in the semi-arid areas of the region is essential for two main reasons. It helps (i) water managers, decision makers and producers to understand its impact and plan appropriate adaptation measures that must be taken ahead of time and (ii) to enhance the scientific community's and other stakeholder's awareness and knowledge of climate change impacts on water use at local level. There is no clear evidence whether the impact of climate change will change the net irrigation requirement of crops in the future in the study area.

Several studies in many parts of the world have analysed the impact of climate change on crop's irrigation water requirement in different regions. However, the majority of the these studies were used low resolution GCMs at large spatial scales (Woznicki 2015). Low resolution GCMs does not account for fine scale heterogenity of climate variability and change due to their coarse resolution (Trzaska and Schnarr, 2014). These studies considered different assumptions of climate scenarios and global circulation models. Results obtained from the GCMs have been reported to have large uncertainties in predicting climate (Diro et al. 2012; Wang 2004; Woldemekel et al. 2012). For example, Zhu et al. (2015) reported that climate change projections using eight global models and three scenarios for the period of 2045 to 2065 showed an increment of the net irrigation requirement of major crops in china. Hopmans et al. (2008) studied the effect of climate change on the future irrigation requirement of crops in California. Their report from two GCMs and three scenarios indicated that changes in total irrigation water requirement as compared to no climate change scenario varied from -13 to +7% for the period of 2070-2099. A study was carried out to estimate the likely impact of climate change on the irrigation water requirement of rice in Bangladesh (Shahid et al. 2011). According to their report, irrigation water demand of rice crop using 16 GCMs and under one climate scenario showed no appreciable change in irrigation water demand. Projections of future climate change in those studies have shown high uncertainty in predicting net irrigation requirement of crops. The reason for the discrepancy of those results could be that Global Circulation Models do not even agree on the sign of future changes let alone their magnitude, consideration of a variety of Global Circulation Models and climate change scenarios by those studies.

Although General Circulation Models (GCMs) are suitable to predict climate at a global and continental level, they have a low resolution at a regional level (Lenderink, et al. 2007; Trzaska and Schnarr, 2014). Results from large-scale studies have little in informing the impact of climate change at smaller scale (Schneider et al. 2008; Brohan et al. 2006). Therefore, downscaling is needed to represent the correct hydrological response at a much finer resolution (Fowler and Kilsby 2007; Dibike and Coulibaly 2005; Wilby and Wigley 2000). Hence, this study can potentially provide valuable information at the small scales level using downscaling approach to improving future irrigation planning in the semi-arid regions of the country and other regions characterised with similar agro-ecology. Since the supply of water in the region is one of the most significant tasks for future water management, investigations on the availability of irrigation water requirement under changing climatic condition are essential. This helps to devise adaptation strategies that can contribute to the sustainable use of water management in the semi-arid region of the country. Therefore, this study aims at (i) determining the change patterns of climatic parameters through the time periods of 2015-2100 and (ii) to quantify the impact of climate change on the net irrigation water requirement using a range of climate change scenarios and General Circulation models (GCMs).

The remainder of this paper is organised into five sections, Section two discusses descriptions of the study area, Section three presents the material and methodologies followed in the study and the remaining sections, four and five describes the result and conclusion of the study, respectively.

2. Study Area

The study area is located in the semi-arid areas of the Tigray region, Northern Ethiopia. Gum-Selasa irrigation scheme, which is located specifically in the south-eastern administrative zone of Tigray region, Hintallo-Wajerat district was taken as a case study. It is found between latitudes of 13°15'45''- 13°13'10''N and longitudes of 39°32'30''- 39°35'00''E and at an average elevation of 2061m above sea level. It is situated at 39 km to the south of Mekelle, Capital city of Tigray region on the road to Addis Ababa.

Common rain-fed crops planted in the irrigation scheme include, Wheat, Teff, Barley and different vegetables, whereas during dry season, farmers practice irrigation and cultivate Maize, Barley, Onion, Tomato and Pepper. The dry season in the study area is about 8 months extended from October to May. Rainfall in the study area therefore tends to be mono-modal in which more than 85% of the rain falling from June to September.

3. Materials and Methods

The hypothesis of this study was climate change has no an adverse effect on the net irrigation water requirement of major crops in the semi-arid areas of Ethiopia. Accordingly, climate data were downscaled from global models (GCMs). The outputs obtained from downscaling were used as an input to the CropWat model to calculate the net irrigation water requirement of the major crops under current and future time periods. In this study, two climate change scenarios: representative concentration paths (RCP_4.5 and RCP_8.5) were assumed for comparison.

a. Data collection

Time series daily climatic data (sunshine hours, maximum temperature, minimum temperature, rainfall, relative humidity and wind speed), crop and soil data were used for predicting future net irrigation water requirement. Those information's were collected from different source and are described in the following sections.

(i) Meteorological data

Historical weather data including daily sunshine hours, maximum tempreture, minimum temperature, rainfall, relative humidity and wind speed of Mekelle station were collected from National Meteorological Service Agency. The long term monthly average of all climatic variables of the station is summarized. Before analysis, the climate data were scanned for errors and filled in gaps based on the procedures given by Hudson and Ruane (2013). The climate data of 1985-2014 periods were used as the reference period for climate change impact assessment.

(ii) Crop and soil data

The crop data required were dates of sowing and harvesting, growth stage duration, rooting depth (cm), crop height (m), critical depletion, yield response factors (Ky) and crop coefficients (Kc). These data were collected from Allen et al. (1998) and Hagos (2005).

The soil property including, soil type, total available soil moisture (mm/m), maximum rain infiltration rate (mm/day), maximum rooting depth (cm), initial soil moisture depletion (%), Total Available Moisture (p) and initial available soil moisture (mm/meter) were collected from the study area and other sources. Major soil type of the study area is Vertisols (Araya et al. 2015) and the texture is dominated by clay (73%) and silt (24%) with high calcium content (20%) and high pH-$_{H2O}$ (8.1) (USDA 1999; Oicha et al. 2010). Initial soil moisture depletion as % TAW (p) was considered as 55% for Maize and 30% for Onion (Allen et al. 1998). This is the average soil moisture water depleted from the root zone before moisture stress. Total available soil moisture (TAW) and readily available soil moisture (RAW) at the root zone were calculated using equation 1 and 2 (Allen et al. 1998).

$$TAW = 1000(FC - WP)Zr \quad (1)$$

$$RAW = p * TAW \quad (2)$$

Where, FC is field capacity, WP is permanent wilting point, P is initial soil moisture depletion as % Total Available Moisture, Zr is the rooting depth and p is critical depletion at the root zone.

b. Downscaling model description

Temperature and precipitation were obtained from fifth phase coupled model inter-comparison project (CMIP5) GCMs using a 30-year baseline daily weather dataset (1985-2014) and two RCPs: RCP_4.5 and RCP_8.5 for the mid (2045-2074) and end of the century (2075-2100). The model HadGEM2‐ES came from the Hadley Centre (Collins et al. 2011), MPI‐ESM‐MR from Max Planck Institute for Meteorology (Raddatz et al. 2007), CCSM4 from national center for atmospheric research (Gent et al 2011), GFDL‐ESM2M from NOAA Geophysical Fluid Dynamics Laboratory (Dunne et al. 2012), and MIROC5 from atmospheric & ocean research institute (University of Tokyo), national institute for environmental studies, and Japan agency for marine-earth science and technology (Watanabe et al. 2011).

The RCPs used in the study are the latest scenarios. Such RCPs have been documented in the IPCC fifth assessment report (Stocker 2014). RCP_4.5 describes intermediate and relatively ambitious scenario while RCP_8.5 describes the high emission scenario and with no policy intervention to reduce emission. These RCPs correspond to the concentrations of CO_2 equivalents of 499 and 571 ppm by the mid of the century and 532 and 801 ppm by the end of the century for RCP_4.5 and RCP_8.5, respectively (Rosenzweig et al. 2013).

Since GCMs have coarse resolution, delta downscaling method of GCMs were applied to represent local conditions. These are bias-corrected using the method of Hempel et al. (2013). The delta method assumes that the model bias will be constant in the future as of the present day simulations (Hamlet 2010). R scripts were applied to prepare delta based scenarios for two periods: the mid (2045-2074) and end of the century (2075-2100). While 20 GCMs outputs from CMIP5 were generated, only five GCM out puts were considered in this study. These downscaling techniques are summarized in many literatures (Rosenzweig et al. 2013; Hudson and Ruane 2013; Rosenzweig et al. 2014; Ruane et al. 2013).

c. CROPWAT model description

From the projections of 5 GCMs, the average increments of maximum and minimum temperature in mid-term and end-term under RCP_4.5 and RCP_8.5 were used as an input to the CropWat model in order to calculate the future net IWR of the major crops in the study area. CropWat model is a decision support tool developed by the land and water development division of FAO (Allen et al. 1998). The model estimates the crop water stress, crop evapotranspiration, yield response to water and yield reduction based on the imbedded simple water balance (FAO 1979; Allen et al. 1998). This model is common and widely used for assessing crop water use because of its less intense data requirements comparing to other dynamic models (Sinclair 2001; Durand 2006). To estimate crop and irrigation water requirement, the model requires a summarized monthly climate, crop and soil physical properties input data. A detail description and requirements of the model are summarized in Smith et al (2002).

Irrigation water requirement for the study area was computed following FAO (1997). The formula is given in Equation 3.

$$\mathrm{IWR} = (\mathrm{Kc} \times \mathrm{ETo}) - \mathrm{Peff} \quad (3)$$

Where, IWR is an irrigation water requirement (mm), Kc is Crop coefficient, ETo is reference evapotranspiration (mm), and P_{eff} is effective precipitation (mm).

Moreover, Effective precipitation (P_{eff}), which is the part of the rainfall effectively utilized by the crop after rainfall losses due to runoff and deep percolation, was estimated using a method given in Smith et al (1992) which was already implemented in the cropwat8 software as given in Equation 4 and 5.

$$Peff = P(125 - 0.2P)/125 \text{ for } P \leq 250 \text{ mm} \quad (4)$$

$$Peff = 125 + 0.1P \text{ for } P > 250 \text{ mm} \quad (5)$$

Where, P is Gross monthly rainfall (mm)

To estimate crop evapotranspiration the model requires reference evapotranspiration values. These values are calculated using the FAO Penman-Monteith equation based on monthly climatic data. The detail descriptions of those equations are found in Allen et al. (1998). Crop evapotranspiration is calculated as given in equation 6. The same equation was used to calculate the current and the projected crop evapotranspiration and thereby irrigation water requirements.

$$Et = Kc \times ETo \quad (6)$$

Where, Et is crop evapotranspiration

In simulating the net irrigation water requirement under extreme rainfall events, analysis of the total rainfall for both historical and future climate change scenarios were carried out to determine the dry and wet years. The rainfall occurring within 20 and 80 percent probability of exceedence represents the wet and dry years, respectively. The values of these parameters were computed following the method in Chow et al, 1998 as given in equation 7.

$$Fa = 100*m/(N+1) \quad (7)$$

Where, Fa is the plotting position, m is the rank number and N is the number of records.

4. Results and Discussion

A. Projected change in Temperature and Rainfall

All GCM models under RCPs 4.5 and 8.5 shows an increasing of maximum temperature in the mid and end terms compared to the baseline. The magnitude of increment was from 1 to 3.9 °C and 0.8 to 6.1 °C from mid to end century, under RCP4.5 and RCP_8.5, respectively. The highest mean increase in maximum temperature was projected by the model HadGEM2-ES (6.1 °C) under RCP_8.5 in end term and the lowest mean temperature increase at the same scenario in mid-term by the model MIROC5 (1.6 °C). Comparing RCP_4.5 scenarios in mid and end century, model HadGEM2-ES projected higher temperature of around 4 °C and the lower increase by the model CCSM4 (1 °C). Both highest and lowest temperature increment by both scenarios were obtained during the wet season. But, model to model uncertainty was visible in predicting dry and wet season temperature. For instant, model MPI-ESM-MR projected high temperature increase during wet season as compared to the dry season in all periods. In contrary, models CCSM4 and MIROC5 projected high temperature increase during the dry season as compared to the wet season. However, the mean ensembles of temperature increment by all GCMs was not significantly different between the wet and the dry seasons. The mean ensemble tempreture increase by 5 GCMs ranged from 1.8 to 4 °C and 1.8 to 4.2 °C in dry and wet seasons from mid-term to end century under RCP_4.5 and 8.5 scenarios, respectively. Pronounced temperature increase has observed under RCP_8.5 towards the end of the century in both seasons.

The same to maximum temperature, the minimum temperature in the study area also projected to increase under all RCPs and all periods. However, the magnitude of increment was slightly higher than the maximum temperature. The mean ensemble minimum temperature increase by all GCMs ranged from 1.9 to around 4.4 °C from mid to end of the century in both dry and wet seasons. The highest increment of 0.4 °C was projected under RCP_8.5 in end term as compared to the maximum temperature under the same scenario. Comparing model to model variation, the model HadGEM2-ES has projected higher minimum temperature increase of about 5.9 and 6.2 °C under RCP_8.5 in end term during wet and dry seasons, respectively and followed by the model MPI_ESM-MR (5.3 and 5 °C), whereas under the same scenario and time period the model MIROC5 showed lower minimum temperature increase of 2.7 and 3 °C in the wet and the dry seasons, respectively. The model CCSM4 in wet season, GFDLSM2M in the dry season and MIROC5 in the wet season under RCP_4.5 in mid-term predicts each the lowest minimum tempreture increase (1.2 °C). All GCMs projected higher minimum temperature increase under RCP_4.5 in end term as compared to RCP_4.5 in mid-term in both seasons.

It shows projected rainfall under two RCPs and five GCMs as percent change from the present period. The models reproduce the annual cycle with the dry season from October to May and wet season from June to September. Comparing to temperature, rainfall projections showed higher variability. For the given time period and emission scenarios, projections from different models may have differences of up to 35% and the variation between the models in simulating rainfall as compared to the baseline was typically significant at p=0.01 as analysed using one way ANOVA statistical test. Looking at the projections, we see that the GCMs disagree on the sign of the projected changes in precipitation among the periods and between dry and wet seasons. The model MIROC5 overestimate the rainfall change during the wet season in future than the present period. It over estimate the rainfall change up to 53% under RCP_8.5 in the end-term and 44% under RCP_8.5 in mid-term. Under RCP_8.5 in the end term, the model MPI-ESM-MR projected the lowest rainfall change (-26%) in wet season followed by CCSM4 (-24%) in the dry season. The model CCSM4 projected decline in rainfall change in the dry season, it also showed an increase in rainfall change ranged from +8 to +15% in the wet season. In addition, the model MIROC5 also projected a decline in rainfall change ranged from -8 to -16% in the majority of the scenarios and time period in dry season and an increase in rainfall change range from 20 to 53% in all time periods and all scenarios in the wet season. In contrary to MIROC5 and CCSM4, the model GFDLSM2M predicts much more rainfall change during the dry season than the wet season. The model HadGEM2-Es projected from no change to decline in rainfall change under RCP_4.5 in end-term and mid-term, respectively and from slight increase to substantial increase in rainfall change under RCP_8.5 in mid-term and end-term, respectively. Despite the high uncertainty in predicting the rainfall change by the models, the mean ensembles of the five models showed that the rainfall change was projected to increase in the future. The substantial increase was about 9% under RCP_8.5 in the end-term during the wet season.

B. Projected change in Reference evapotran spiration

Many climate impact studies focus on precipitation and temperature change. However, it is also important to focus on change in reference evapotranspiration (ETo) in combination of precipitation, because this gives an indication of possible changes in water stress (Terink et al, 2013). It represents each of five GCMs of ETo for the mid-term (2045-2074) and end term (2075-2100) under RCP 4.5 and RCP 8.5 for two seasons. The error bars showed one standard division (SD) around each mean values which describes inter-seasonal ETo variations. The projected change ETo under RCP_8.5 in the end-term was higher in the range from 7 to 17% and 6 to 14% and under RCP_8.5 in mid-term range from 4 to 10% and 4 to 9% by all GCMs in dry and wet seasons, respectively. Similarly, ETo under RCP_4.5 in end-term was higher as compared to RCP_4.5 in the mid-term by all GCMs. The projected ETo changes in dry season (October-May) for future period changes are larger in magnitude than the projected changes in wet season (June-September). However, the change of ETo between the two seasons is not significant (< 2%). The largest increase of 17% was projected by the HadGEM2-ES model and the smallest 7% was projected by the MIROC5 both under RCP_8.5 in end term period in the dry season. Model HadGEM2-Es also showed higher ETo 11% under RCP_4.5 in end term as compared to RCP_4.5 in mid-century 8%. The smallest increase 3% was projected by the model CCSM4 under RCP_4.5 in mid-term during the wet season. The increase in ETo is more significant at the end of the century for all GCMs under scenario RCP_8.5. This clearly shows that an increased demand of water in the future.

C. Implications of climate change on irrigation water requirement

C.1 Irrigation water requirement in dry season crops

The response of IWR of Maize and Onion crops to climate change using simulated climate parameters is summarized. The results reavealed that an increasing of net IWR by all GCMs in all time periods for both crops compareing to the baseline scenario (1985-2014). The mean net IWR increased by 6%, 8%, 8% and 12% for both crops under RCP_4.5 in mid-term and end-term and RCP_8.5 in mid-term and end-term, respectively. Predictions from different models may have differences up to 29% (GFDL-ESM2M +3% under RCP4.5 in mid-term and CCSM4 & MPI-ESM-MR +14% under RCP8.5 in end-term) for Maize crop and up to 40% (MIROC5 +4% under RCP4.5 in end-term and GFDL-ESM2M & MPI-ESM-MR +15% under RCP8.5 in end-term) for Onion crop. On an average (considering mean ensembles of all GCMs) in end-term under RCP_8.5, the net IWR will be increased by 12% as compared to the baseline scenario for both crops, while in the case of mid-term under RCP_4.5, projections are higher by about 6%. Such increase will bring a further challenge in the future for local farmers to cope with the limited amount of water availability in the area especially towards the end of the century.

C.2 Irrigation water requirement under dry and wet years

To simulate the net IWR of the two crops in two selected climatic conditions, analysis of total rainfall were conducted to determine wet and dry years at 20 and 80 percent probability of exceedence. It was showed the simulated net IWR under dry and wet conditions.

It showed the percent change of the net irrigation water requirement from the baseline (1985-2014) for the two crops under dry and wet years. Results showed that increasing of net IWR by all GCMs and all time periods for both crops as compared to the baseline. The net IWR using mean ensembles of GCMs was ranged from 7-13% from mid to end-term period in reference to the baseline for both crops. RCP_8.5 in end term showed higher net IWR as compared to the others. Least net IWR was observed under RCP_4.5 in mid-term. The net IWR between wet years and dry years showed no statistically significant difference for both crops at p=0.05 using 2 tailed student t significant test. This implies that the effect of the rainfall obtained during the growing season from wet years is not significant when compared to rainfall obtained from dry years. This indicates that the increasing of the net IWR could be due to the increasing of temperature in the future and little contribution of the future rainfall during dry season. Therefore, there is a need to supplement irrigation even in a wet year.

Predictions from GCM models using one way ANOVA showed a very high significant difference at p=0.01 and very high significant at p=0.001 for Maize (p=0.01) and for Onion (p=0.001) crops. These differences can be up to 36% (ranged from +4 to +17%) and 47% (ranged from+4 to +18%) for Maize and Onion crops, respectively. Predictions from all GCMs showed an increased in net IWR under both scenarios and time period. The largest increment (17%) was observed by the model MPI-ESM-MR for Maize crop and 18% by the models GFDLSM2M, HadGEM2-ES and MPI-ESM-MR for Onion crop under RCP_8.5 in end-term. The smallest net IWR was projected by the model GFDLSM2-ES under RCP_4.5 in mid-term in the wet year for maize crop and by the model MIROC5 under RCP_4.5 in end term in the wet year for Onion crop. However, the mean ensemble by all GCMs projected an increase in net IWR ranged from +7 to 13% from mid to end century for both crops.

5. Conclusions

A comparison between the baseline period (1985–2014) and the future mid-term (2045-2074) and end-term (2075-2100) clearly showed that climate change would lead both rainfall and the temperature to rise which can cause the net irrigation water requirement to increase significantly during cropping seasons in the future.

Downscaled climate change scenarios revealed that both the maximum and minimum temperature will increase in the future. The minimum temperature showed slightly higher than the maximum temperature. The largest increment was projected to be around 0.4 ^{o}c under RCP_8.5 in the end term. Temperature projections by all GCMs under RCP_8.5 are much higher than those predicted under RCP_4.5.

Projected changes in rainfall showed higher variability than the projected temperature. Analysis using one way ANOVA showed that predictions from five models may have differences of up to 35% and the variation in simulating rainfall between the models was statistically significant at p=0.01 significance level. The projected rainfall by different GCMs varied from about -26 to +53%. However, the ensemble mean of all GCMs varied from no change under RCP_4.5 to 9 % change under RCP_8.5 from mid to end of the century.

Net irrigation water requirement was projected to increase by all GCMs under all scenarios and in all time periods for both crops compareing to the baseline (1985-2014). Predictions from different models showed net IWR difference up to 29% and 40% for Maize and Onion crops, respectively. However, considering mean ensembles of all GCMs in end-term under RCP_8.5, the net IWR was projected to increase by 12% for both crops as compare to the baseline while in the case of mid-term (2045-2074) under RCP_4.5 it was projected to increase by about 6%. The obtained results explicitly showed that availability of irrigation water in the study area and other similar agro-ecologies will be jeopardized in the future.

Although models have uncertainties in the prediction process, the results obtained in this study can provide preliminary informations about the potential impact of climate change on irrigation water requirement of Gum-Selasa irrigation scheme in particular and for the semi-arid regions of Ethiopia in general. The results obtained from this study can potentially enhance users understanding of climate change. Moreover, it is also essential for water managers and producers to understand its impact and devise adaptation measures that must be taken ahead of time. Despite the fact that water resources is very much limited, agricultural water management in this region is very poor. Hence, the authors of this study would like to recommend farmers, water managers, water use associations and decision makers should work towards improving water use efficiency in the future.

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